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A COMPUTER COST ANALYSIS TECHNIQUE FOR DETERMINING THE OPTIMUM TRANSPORTATION SYSTEM FROM VARIOUS PULPWOOD HARVESTING LOCATIONS TO A SINGLE PULP MILL

A THESIS

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Larry Elwood Dix

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A COMPUTER COST ANALYSIS TECHNIQUE FOR DETERMINING THE OPTIMUM TRANSPORTATION SYSTEM FROM VARIOUS PULPWOOD HARVESTING LOCATIONS TO A SINGLE PULP MILL

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TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		ii
LIST OF TABLES		v
LIST OF ILLUSTRATIONS		vi
SUMMARY		vii
Chapter		
I.	INTRODUCTION	1
	Purpose Background General Nature of the Problem Study Objectives Scope and Limitations	
II.	LITERATURE SEARCH	11
	Trends Future Conditions Previous Attempts to Compute Transportation Costs Conclusions	
III.	PROCEDURE	16
	An Iterative Approach to the Problem System Variables Transportation Options A General Linear Programming Approach	
IV.	DESCRIPTION OF THE MODEL	29
	General Description Specific Procedures	
V.	DESIGN AND RESULTS OF EXPERIMENTS	39
	Introduction Derivation of Data Results of Experiments	

TABLE OF CONTENTS (Continued)

Chapter		Page
VI.	USE OF THE MODEL	56
	General Comments Impact of the Current Situation Changes in the System Over Time Volume Considerations	
VII.	CONCLUSIONS AND RECOMMENDATIONS	58
	General Conclusions Recommendations	
APPENDIX		61
A.	PROGRAM TERMINOLOGY	61
B.	THE PROGRAM	69
C.	SAMPLE PROGRAM OUTPUT	82
BIBLIOGRAPHY		90

LIST OF TABLES

Table		Page
1.	Current Variable Capacity	32
2.	Vehicle Load-Unload Times	42
3.	Truck Capacities	42
4.	Fuel Data	43
5.	Constants Used In Experiments	45
6.	Forest Data For Experiment One	46
7.	Between-Forest Dealer Data For Experiment One	46
8.	Forest Data For Experiment Two	47
9.	Between-Forest Dealer Data For Experiment Two	47
10.	Forest Data For Experiment Three	48
11.	Between-Forest Dealer Data For Experiment Three	48
12.	Forest Data For Experiment Four	49
13.	Between-Forest Dealer Data For Experiment Four	49
14.	Results Of Experiment One	50
15.	Results Of Experiment Two	51
16.	Results Of Experiment Three	52
17.	Results of Experiment Four	53

LIST OF ILLUSTRATIONS

Figure		Page
1.	Typical Mill And Forest Areas	17
2.	Transportation Options 1 through 4	22
3.	Transportation Options 5 through 8	23
4.	Transportation Options 9 through 12	24
5.	Transportation Options 13 through 15	25

SUMMARY

This research was undertaken in conjunction with a research grant awarded to the School of Industrial and Systems Engineering at Georgia Institute of Technology by the Southern Executives Association to study the systems aspects of pulpwood harvesting and transportation. The objective of this thesis is to study various truck and rail pulpwood transportation systems and develop a method by which a pulpwood mill could evaluate their utility in specific situations.

To accomplish this objective a digital computer model is used to compute the transportation cost of shipping wood from forest landings to the mill by 15 different methods. These methods include various combinations of longwood, shortwood, palletized, unpalletized, truck and rail transportation either from the forest landing directly to the mill or via an intermediate location. The model is not limited to linear relationships but also includes non-linear functions and step functions.

The model developed could be used by a pulpwood mill to study their present transportation situation and to simulate future systems. The input data required is cost information particular to a mill's operating area, the locations of their forest resource areas, and the location of intermediate dealers.

Further research is recommended in this area to include modes of transportation not considered in this study and the expansion of the model to include constraints due to volume.

CHAPTER I

INTRODUCTION

Purpose

The pulp and paper industry has experienced rapid growth during the past two decades. Production of paper and paperboard reached a new high of approximately 53.5 million tons in 1969, a six percent increase above 1968's previous high (1). Pulpwood consumption is expected to reach 70 million cords by 1975. The paper industry currently ranks fifth in the United States, among the largest manufacturing industries, being exceeded only by iron and steel, machinery, automobiles, food, and textiles.

Accompanying this growth in the pulpwood industry have been many changes in the transportation methods used to get the wood from the harvesting area to the woodyard at the mill. The transportation system has progressed from the use of animal and mechanical power, to the current system which is essentially completely mechanized.

The cost of pulpwood transportation by these mechanized means has become a major factor in the total pulpwood production costs. Dyer (2) states that woodhandling-from the stump to the digesters or grinders-comprises the highest direct labor charges of any sector in the paper making process. In addition, the rapidly rising cost of manufacturing pulpwood harvesting and transportation equipment have reached the point where the selection of the proper equipment by the pulpwood producer is a necessity. Careful consideration should be given to the transportation method selected to deliver wood from the harvesting area to the mill yard.

The two major methods of pulpwood transportation are by truck and by railroad. At present, trucks are used up to a distance of 35 to 75 miles from the mill. Beyond that distance, rail carriers are generally used. The objective of this research is to study the pulpwood transportation system as related to truck and rail transport and to determine what parameters affect the costs of these systems. From this information, a computer program is developed which accepts data concerning a specific pulpwood mill and determines, given specific options, the most economical method of wood transportation from the harvesting area to the mill.

The importance of solving such a problem lies in the area of cost minimization. Since transportation costs comprise a significant portion of the cost of wood delivered to the mill, it is important to study the transportation system and determine in what areas these costs can be reduced.

Background

Harvesting and transportation of pulpwood has followed the same basic line of evolution as agriculture. In its early stages, manual labor with hand tools and animal power predominated. These early harvesting methods were gradually replaced by light machinery and power tools. Heavy equipment is currently replacing much of the light machinery and small power tools (3). Silversides (4) predicts that one of the effects of such mechanization in the forest will be the change from relatively free men, working as independent procedures with comparatively little supervision and with pay in accordance with their output, to wage earners. Free men do not normally have the capital and are not able to earn enough to be able to invest in costly machinery for themselves. Of the wood currently consumed by the United States pulp and paper industry, less than 25 percent comes from company owned land while the remainder is obtained from farmers and government owned land. Some pulpwood is also imported from Canada. The current general policy is to hold company owned forests in reserve against future price increases (5).

There are three general systems of pulpwood procurement: Paper or pulp company operations, direct producer operations, and dealer operations.

Paper or pulp company operations produce a relatively small fraction of United States production and are significant, in terms of volume, only in the Northeast and Pacific Northwest (6). In the Southeast, these company operations are maintained by many companies primarily for training and experimental purposes rather than for their actual production value. These operations try out new harvesting methods and equipment.

Direct producer operations account for 15 to 20 percent of pulpwood purchases by the mills. In this type of operation an individual producer sells his pulpwood directly to the mill through the woodlands division which acts as the mill's purchasing agent.

In the dealer operation, individual pulpwood producers sell their pulpwood to a dealer who is acting as a collecting agent. The dealer then sells his pulpwood, which has been gathered from several producers, to the mill.

The Southern pulpwood producing region which extends from Virginia south to Florida and west to Texas produces more than 60 percent of the United States' pulpwood production (6). Approximately 80 percent of the trees harvested in this region are southern pines, the remainder being made up of various types of hardwood. The main procurement method used by the mills in this region is the dealer system with the mills generally keeping a 12 to 18 day supply of wood on hand. The reason for this low inventory is that stored wood will deterioriate in the warm, humid climate of the South, thus reducing its paper-making qualities.

A warm climate and favorable ground conditions allow year around harvesting operations with a few interruptions due to bad weather. The Southern region has an excellent system of roads and the terrain is generally favorable to logging operations.

Pulpwood transportation systems may be divided into two main classifications: truck haul and rail haul. Pulpwood which originates within truck hauling distance of the mill is delivered directly from the woods by truck. In some regions the maximum truck hauling distance is 35 miles. In other areas it may be more economical to use trucks up to a distance of 75 miles. The differing economical distances for truck hauling may be caused by any or all of the following factors: differing labor rates, various speeds at which the trucks may travel, differing truck capacities or the availability of rail transportation.

For distances farther from the mill, intermediate points known as truck or rail woodyards may be located. These woodyards are used as concentration points for smaller shipments of wood to be loaded on rail cars or larger trucks for final delivery to the mill. These forest to mill systems may or may not use pallets.

Pulpwood is transported either as shortwood or as longwood. For this research, shortwood has been defined as those logs which do not exceed five feet three inches in length, which is the maximum allowable length for rail shipment. Longwood is considered any wood in excess of five feet three inches in length up to a full tree length. The decision as to whether to use a shortwood system or a longwood system deserves careful study since each has its particular advantages.

The shortwood system's greatest advantage is flexibility. It can be used in almost any logging situation regardless of terrain. The shortwood system can harvest any size tree; large, small, tall, or short. The shortwood system is highly mobile, requiring relatively little effort to move the operation from one location to another. This is of particular importance to the producer who is operating in several scattered harvesting areas. Minimum financial outlay is required for most partially mechanized shortwood harvesting and transportation systems. It is possible to be an active pulpwood producer for the price of a chain saw and a used hauling truck.

The primary disadvantage of shortwood systems is the reliance on manual labor for its ability to adapt to various logging situations. Not only is the price of manual labor increasing but the number of people willing to work at any price in this type of job is decreasing.

Nearly all pulp mills are geared to the use of shortwood at the mill. Except in the West, most mills now use a drum type debarker which accepts only shortwood. To change this equipment at the woodyard or to convert longwood into shortwood at the mill would require a considerable amount of investment. This, along with rail rate advantages for shortwood transportation, indicate that the shortwood transportation system will continue to compete with other methods.

In general, longwood systems have the advantages of: lower overall manpower requirements, fewer days lost due to bad weather, better utilization of an entire tree, and an attraction of more highly skilled personnel.

The greatest disadvantage of the longwood system is that it cannot be used for all types of stumpage. Small trees generally do not make a profitable longwood operation. The bigger the average tree dimensions, the greater the efficiency of the longwood system. Due to the high equipment investment, a longwood system must operate at a high efficiency to be profitable (6).

General Nature of the Problem

Prince (7) contends that the pulpwood industry is inclined to regard the transportation of pulpwood from the forest to the mill as a service to be purchased from a public carrier at prevailing rates, and to ignore the machine hour productivity and employment of the machines utilized in this phase of transportation. Much of the effort to reduce freight rates has depended on the extent to which alternative transportation systems can meet the competition of existing systems. There is little cooperation between the carrier and the mill offering an efficient transport system which will provide greater rewards to the shipper.

This situation can easily be seen in the Southern pulpwood producing region where such a high percentage of the wood is bought by the mill "at the entrance of the woodyard" from the producer or dealer. The price paid includes the price of transportation no matter how efficient that transportation system might be. Little attention has been paid to the alternative transportation systems that might have been used.

Increased mechanization of harvesting machinery, the accompanying increase in the amount of capital or cash expenditures required by a producer, and the increase in the demand for pulpwood are all seen as reasons for basic changes in the method of pulpwood procurement. The method may change from one in which the mills buy wood from producers or dealers at the mill woodyard to a system by which the mill has substantial interest in the ownership and control of, not only the mill process itself, but also the harvesting and transportation systems as well (8) (9). Such an integrated procurement system should allow more efficient response to the needs of the mill management and thus create a more efficient operation of the entire procedure (3).

From the viewpoint of the mills, control over a substantial portion of the raw material is mandatory. By having this control, the mill would be better able to obtain the required volume of wood without damaging volume or inventory fluctuations.

As the pulpwood procurement system tends to evolve from one which primarily consists of independent producers and dealers to one which is primarily company managed, the company management would be extending its scope of influence from the mill into the forest and harvesting areas to a greater degree than at present. Part of this expansion would require the mill management to consider in more detail, decisions concerning the method by which wood should be brought from the harvesting area to the mill. Such questions must be considered as: Should truck or rail transportation be used? What size truck is most efficient for the particular company situation? Should wood be palletized?

Study Objectives

From the foregoing description of the background and general nature of the problem, it can be seen that pulpwood mill management may soon be faced with the design and implementation of a transportation network which could be integrated into a mill's operations at the lowest possible cost. The overall objective of this research is to study various pulpwood transportation methods and develop a method to evaluate their utility in specific situations.

The specific objectives of this study in the order of their investigation are:

(1) Determine the various feasible pulpwood transportation methods and isolate the costs associated with these methods.

(2) Develop a digital computer model which will accept input data, including non-linear relationships, from a selected mill, compute the cost of pulpwood transportation from various locations, and determine the minimum cost options.

(3) Utilize the computer model to analyze the transportation costs of a typical pulpwood mill.

(4) Develop a generalized method of using the computer model in any mill situation.

Scope and Limitations

The computer model developed in this study considers 15 transportation alternatives from a maximum of four forest areas each of which contains up to six working landings and the transportation alternatives from intermediate truck and rail dealer yards located outside the forest areas. The model can be easily expanded to consider more locations by increasing the applicable array sizes.

The model considers only truck and rail transportation of longwood or shortwood. No consideration is given to barge transportation or the shipment of chips either by surface systems or pipe lines.

The following assumptions were made in modeling the pulpwood transportation systems:

(1) Truck transportation will be either on three cord or ten cord capacity trucks (the model can be altered to consider other sizes).

(2) Rail costs are those which are charged by railroads according to Interstate Commerce Commission approved tariffs.

(3) Only shortwood will be shipped by rail.

(4) Palletized systems will only be considered when more than one type of vehicle is used to transport wood from the landing to the mill, thus necessitating a transfer operation.

(5) Transportation is considered as that hauling accomplished from the forest landing to the mill woodyard whether or not via an intermediate truck or rail dealer.

(6) All wood delivered to the mill woodyard will be in the form of shortwood. In cases where longwood is delivered by truck to the mill, it will be sawed into shortwood at the mill yard and this cost will be considered as part of the cost being computed.

The computer model considers the following in computing the transportation cost:

(1) Bucking--the sawing of logs into a specific size, depending on the method of transportation used.

(2) Loading--the placing of wood onto the vehicle used in hauling.

(3) Hauling--the movement of wood from one location to another. The rail hauling rates are from Interstate Commerce Commission tariffs, while trucking costs are made up of the fixed and variable costs associated with typical truck operation.

(4) Transfer--the shift from one type of vehicle to another during shipment.

(5) Pallets--the fixed and variable costs of pallets, if used.

(6) Unloading--the removal of wood from the vehicle at the mill woodyard.

CHAPTER II

LITERATURE SEARCH

Trends

The general policy now in effect in the pulpwood industry is to obtain the majority of their wood from farmers and government land while holding their own stands in reserve as a buffer against price increases. Prediction on the trends in this area indicate that pulpwood companies will probably acquire more land for use in harvesting which should result in a greater percentage of wood coming from company owned land (3) (8) (9). As this system develops, the individual mills will probably be required to exercise more control over the type of transportation used rather than relying on firms beyond the company's control making the determination of the mode of transportation.

In commenting on the results of mechanization on the pulpwood harvesting area, Silversides (4) states that distance is an increasingly important factor in harvesting. With increased performance by transportation carriers over longer distances, it has been possible to maintain, and in some cases reduce the costs incurred in harvesting and transporting wood. This has been brought about by the larger volumes and higher speed at which it is possible to produce and transport wood resulting in a lower unit cost.

Prince (7) predicts other trends that are expected to develop in the use of truck and rail deliveries. When using trucks as the mode of transportation there is the necessity to select the proper type of equipment and to compute the maximum machine hour productivity. The current trend is toward larger loads where the load is not limited by highway regulations. Trends toward the use of longer tree lengths poses a problem of concentrating manageable loads to the cubic available space which can greatly vary the cost per cord or the cost per ton/mile.

Truck cycles can lead to bunching of arrivals at the mill where further delays in accounting and scaling tends to compound the problem of efficiency of wood handling. When wood is bought on a delivered basis, there is a tendency to overlook the efficiency of the seller's transportation system which results in the buyer often paying a price for the wood in excess of what the transportation cost dictates.

In the rail delivery system, whether truck competitive or water competitive, the final optimum rate depends on the utilization of equipment in all aspects--weight carried, use of cubic capacity, car cycle and length of employment. If rail deliveries could be put on a daily flow basis rather than a weekly batch method, which requires a concentration of cars for long periods, the proper flow pattern for wood movement might be improved.

Davis (11) states that the availability of transportation facilities exerts a powerful influence on the organization of a forest. Pulpwood transportation from stump to mill is the limiting factor in many areas. Developing a harvesting area which has access to good roads or waterways can change the entire administrative situation of the forest area supporting a particular mill. In such a situation, forest subdivision is largely controlled by transportation. Although transportation modes, such as rail, truck or barge, are naturally related to topography, they are only partially controlled by it.

Future Conditions

Rogers (8) concluded that the present pulpwood procurement system is, in the long run, uneconomical as it depends on low rates of production from producers harvesting small, poorly stocked stands. Such a system is not responsive to fluctuating raw material demands as it possesses built in time lags which negate responsible management control.

An integrated procurement system made up of company owned or managed harvesting areas could provide economic benefits as a result of efficiencies of increased scale, unit load handling and transportation, and improved management control. Such systems should be more responsive to demand fluctuations and control over the flow process would, in reality, become an added responsibility of corporate management.

In addition to the individual mills owning or controlling a greater percentage of their individual harvesting areas, these areas should be consolidated in order to derive cost savings from minimizing transportation distances and increased efficiency in the management of the materials flow. The redistribution of primary land to supply the individual mill could come about by lease, rental, or purchase of properties joining together land ownership patterns.

Previous Attempts to Compute Transportation Costs

The current methodology employed to compute transportation costs is to use the average cost per mile for the type of vehicle used. For example, the current figure used in the pulpwood industry for the cost of operating a three cord truck is fifteen cents per mile. Such a method is used by Hamilton, et al (12) in computing hauling costs. The procedure used is shown in formula 1.

$$CH = \frac{CPMxLOH+WPHxMOH/MPH}{SAL} \tag{1}$$

Where

CH = Hauling cost per cord

CPM = Cost per mile for truck type and road surface

LOH = Length of haul in round trip miles

WPH = Wage per hour cost

MOH = Miles of haul

MPH = Miles per hour over road surface

SAL = Size of an average load

While such a computation may yield a gross approximation of hauling costs, there are several shortcomings to this method. First, using CPM x LOH assumes that all costs associated with the truck operation vary with the distance traveled. While this may be true for such items as gas, tires, lubrication and possibly maintenance, it is not a valid assumption when considering the write-off of investment. This cost would be better computed on a daily basis and proportioned according to the number of cords carried per day by the truck. Second, this algorithm assumes a constant truck velocity from the stump to the mill. An improvement to the aformentioned model would be an expansion to take into account the different operating speeds encountered such as the five to ten miles per hour average in the woods and on unimproved back roads to the 40 to 50 miles per hour that can be maintained on the open road. The velocity relationship developed in this investigation uses a non-linear step function.

The proceeding model is typical of the tools used in the pulpwood industry to compute hauling costs. While it yields an approximation of the cost desired, a more accurate algorithm with more exacting calculations is needed if management is going to make meaningful decisions based on the output of such algorithms.

One of the paper companies investigated uses a revised simplex linear programming algorithm as an aid in determining where to buy wood. This model considers the amount of wood needed, the price of wood at each source and the associated transportation costs. However, these transportation costs are based on a fixed cents per mile rate.

Conclusions

The results of the literature survey show that numerous publications are devoted to describing the importance of an efficient transportation system but little work has been done on developing a management tool which will enable a pulpwood mill to accurately evaluate the transportation methods that may be available. The work that has been done is based too much on average costs.

This research is expected to yield a method by which management can accurately analyze their transportation system without resorting to the use of average costs per mile for various carrier systems. In addition, the method developed computes the cost of up to 15 different transportation alternatives for comparison.

CHAPTER III

PROCEDURE

An Iterative Approach to the Problem

To accomplish the objectives of this investigation, a specific pulpwood transportation system must be designed and analyzed. The system chosen consists of a pulpwood mill which receives wood from up to four separate forests, each containing up to six landings. Truck and rail dealer locations may be placed within or outside the forest areas. Figure 1 depicts a typical mill and forest area. Cost relationships were investigated to determine what parameters influence the cost of transporting pulpwood from the harvesting area to the mill yard. The costs investigated begin with the loading of wood at the forest landing and end with the delivery of the wood to the receiving area of the mill yard.

With a particular system well defined, it is then possible to formulate a set of relationships to describe the costs involved in transporting wood by various alternative methods. Fifteen methods of transportation were isolated for study by using various combinations of truck and rail transport with options included for palletizing shortwood.

After quantifying the problem, a computer model was constructed to represent the overall process. The purpose of this model is to accept data concerning a mill, such as number and distance of primary forest areas, and to compute the cost per cord of the transportation options

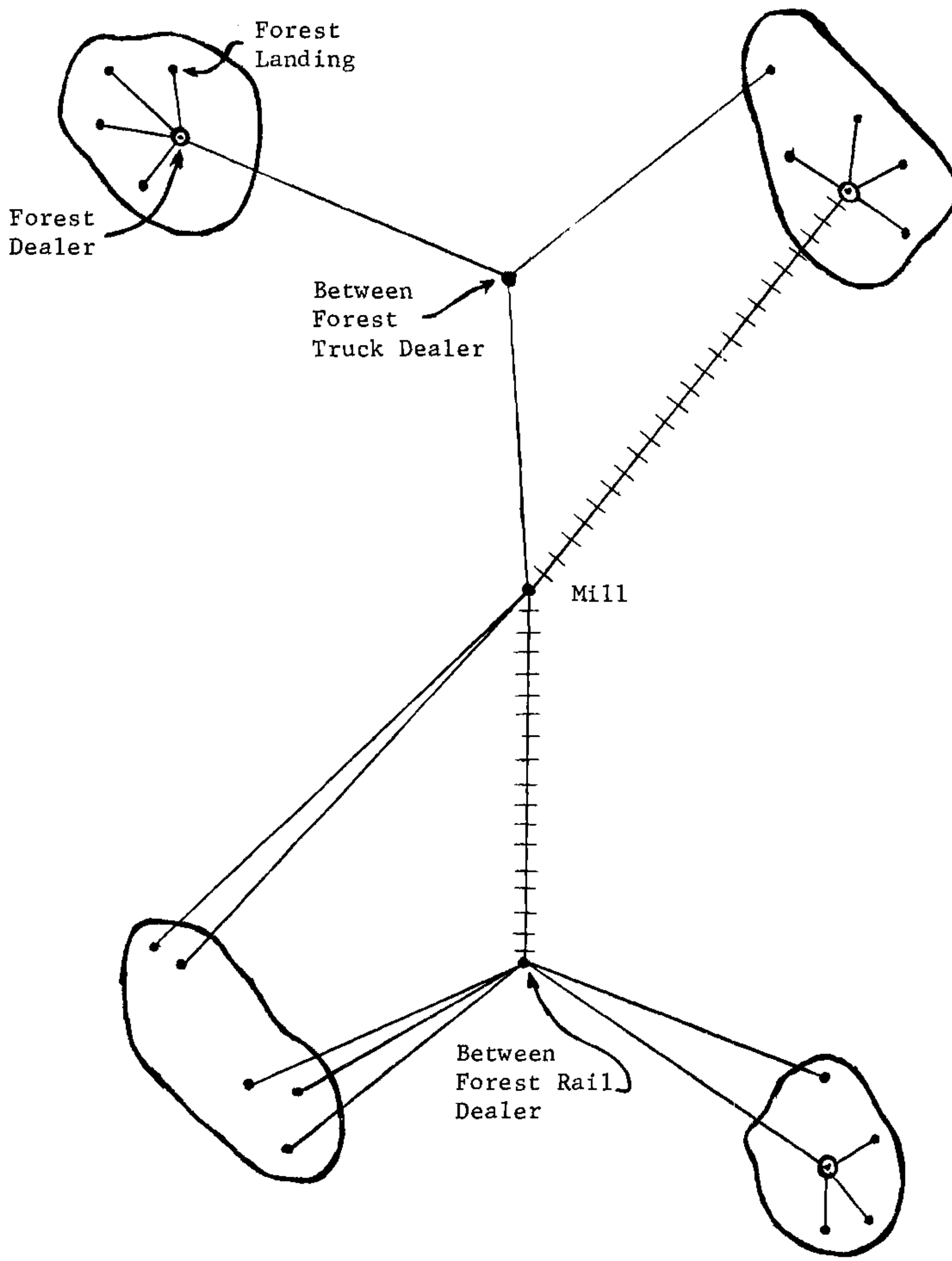

Figure 1. Typical Mill and Forest Areas.

selected. The language chosen for the computer model was Extended ALGOL. This language is efficient at making repetitive mathematical calculations and its use of procedures enhances the ease of programming the pulpwood transportation problem.

The model was first run several times to detect and eliminate logical and programming errors. When the model appeared to be performing satisfactorily, several runs were made using typical mill situations which varied the distance between mill, forest, and dealer locations in order to determine what conditions would cause the least cost option to shift from one transportation method to another.

System Variables

The system variables used in this model are hypothetical and are not intended to represent any particular mill system now in being. An attempt has been made to keep all data realistic, and the values used could be realized by the use of existing equipment. The use of this model by a particular mill would require that mill to insert its own values for the variables.

The initial function to be considered is that of bucking or sawing. All shortwood is considered bucked in the woods by chain saw. Since all wood delivered to the mill is assumed to be shortwood, any longwood must be cut into shortwood prior to final unloading. Longwood which is brought to an intermediate point for rail transportation would be cut into shortwood by a slasher which cuts an entire load while it is still on the truck. Longwood delivered to the mill by truck would be cut into shortwood by the same slashing method.

The initial loading function performed at the forest landing can be in the form of shortwood or longwood. In the case of shortwood, the loading may be onto a three cord or a ten cord truck which may be palletized or unpalletized. Unpalletized shortwood is assumed, for the purposes of testing the model, to be loaded by the use of a Big Stick loader. Longwood and palletized shortwood are loaded by crane with a hydraulic grapple. Any loading technique, properly costed, could be inserted in placed of the selected methods in the model.

All truck hauling is assumed to be with three cord or ten cord trucks at various speeds. The first speed considered is on unimproved roads in the forest area. These speeds range from two to ten miles per hour for distances of one to five miles. The second speed considered is an improved road within the forest area. Speeds in this area can range from ten to 30 miles per hour for distances of five to 25 miles depending on road conditions and the size of the forest. The final speed to be considered is that which can be maintained on the open road. These speeds can vary from 40 to 60 miles per hour for distances of 20 to 200 miles.

Some transportation options require the transfer of wood from one type of vehicle to another. The following types of transfer were considered:

(1) Shortwood, unpalletized, from three cord truck to ten cord truck.

(2) Shortwood, palletized, from three cord truck to ten cord truck.

(3) Shortwood, unpalletized, from three cord truck to railroad.

(4) Shortwood, palletized, from three cord truck to railroad.

(5) Shortwood, unpalletized, from ten cord truck to railroad.

(6) Shortwood, palletized, from ten cord truck to railroad.

The unloading function is assumed to be by crane from the following types:

(1) Shortwood, unpalletized, from a three cord truck.

(2) Shortwood, unpalletized, from a ten cord truck.

(3) Shortwood, palletized, from a ten cord truck.

(4) Shortwood, unpalletized, from a railroad car.

Transportation Options

The following transportation options are considered by the computer model as possible methods which could be used to transport wood from the harvesting area to the mill:

(1) Shortwood, unpalletized, from the forest landing to the mill by three cord (bobtail) truck.

(2) Shortwood, unpalletized, from the forest landing to the mill by ten cord truck.

(3) Shortwood, unpalletized, from the forest landing to the forest dealer on a three cord truck--from the forest dealer to the mill on a ten cord truck.

(4) Shortwood, palletized, from the forest landing to the forest dealer on a three cord truck--from the forest dealer to the mill on a ten cord truck.

(5) Shortwood, unpalletized, from the forest landing to the forest dealer on a three cord truck--from the forest dealer to the mill by rail.

(6) Shortwood, unpalletized, from the forest landing to the forest dealer by ten cord truck--from the forest dealer to the mill by rail.

(7) Shortwood, unpalletized, from forest landing to between-forest

truck dealer by three cord truck--from between-forest truck dealer to mill by ten cord truck.

(8) Shortwood, palletized, from forest landing to between-forest truck dealer on three cord truck--from between-forest truck dealer to mill by ten cord truck.

(9) Shortwood, unpalletized, from forest landing to between-forest rail dealer on three cord truck--from between-forest rail dealer to mill by rail.

(10) Shortwood, unpalletized, from forest landing to between-forest rail dealer by ten cord truck--from between-forest rail dealer to mill by rail.

(11) Shortwood, unpalletized, from forest landing to forest dealer on three cord truck--from forest dealer to between-forest rail dealer by ten cord truck--from between-forest rail dealer to mill by rail.

(12) Shortwood, palletized, from forest landing to forest dealer on three cord truck--from forest dealer to between-forest rail dealer by ten cord truck--from between-forest rail dealer to mill by rail.

(13) Longwood, from forest landing to mill by ten cord truck.

(14) Longwood, from forest landing to forest dealer by ten cord truck--from forest dealer to mill by rail. Longwood is cut into shortwood at the forest dealer.

(15) Longwood, from forest landing to between-forest rail dealer by ten cord truck--from between-forest rail dealer to mill by rail. Longwood is cut into shortwood at the rail dealer.

Options 1 through 15 are depicted in Figures 2 through 5.

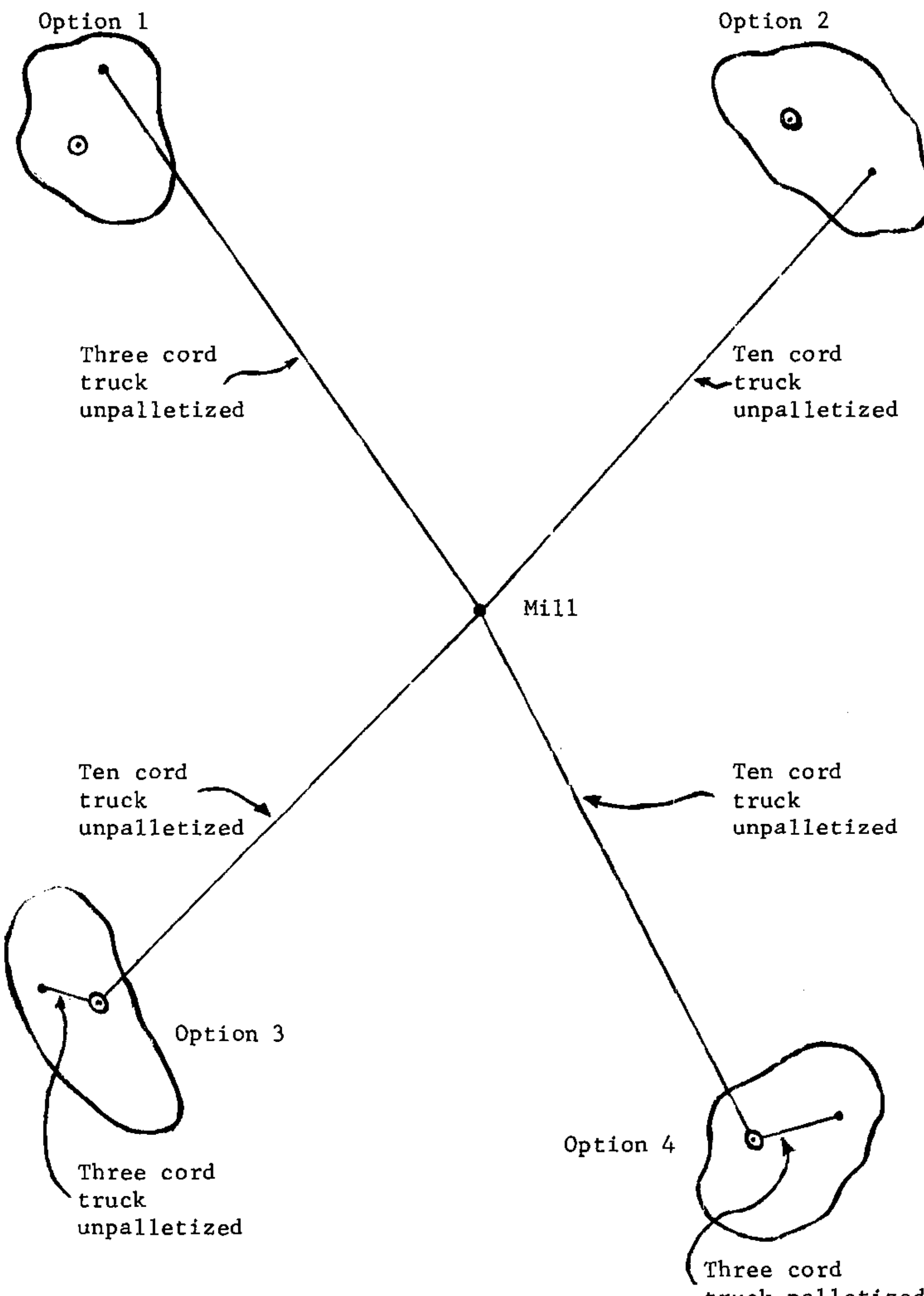

Figure 2. Transportation Options 1 through 4

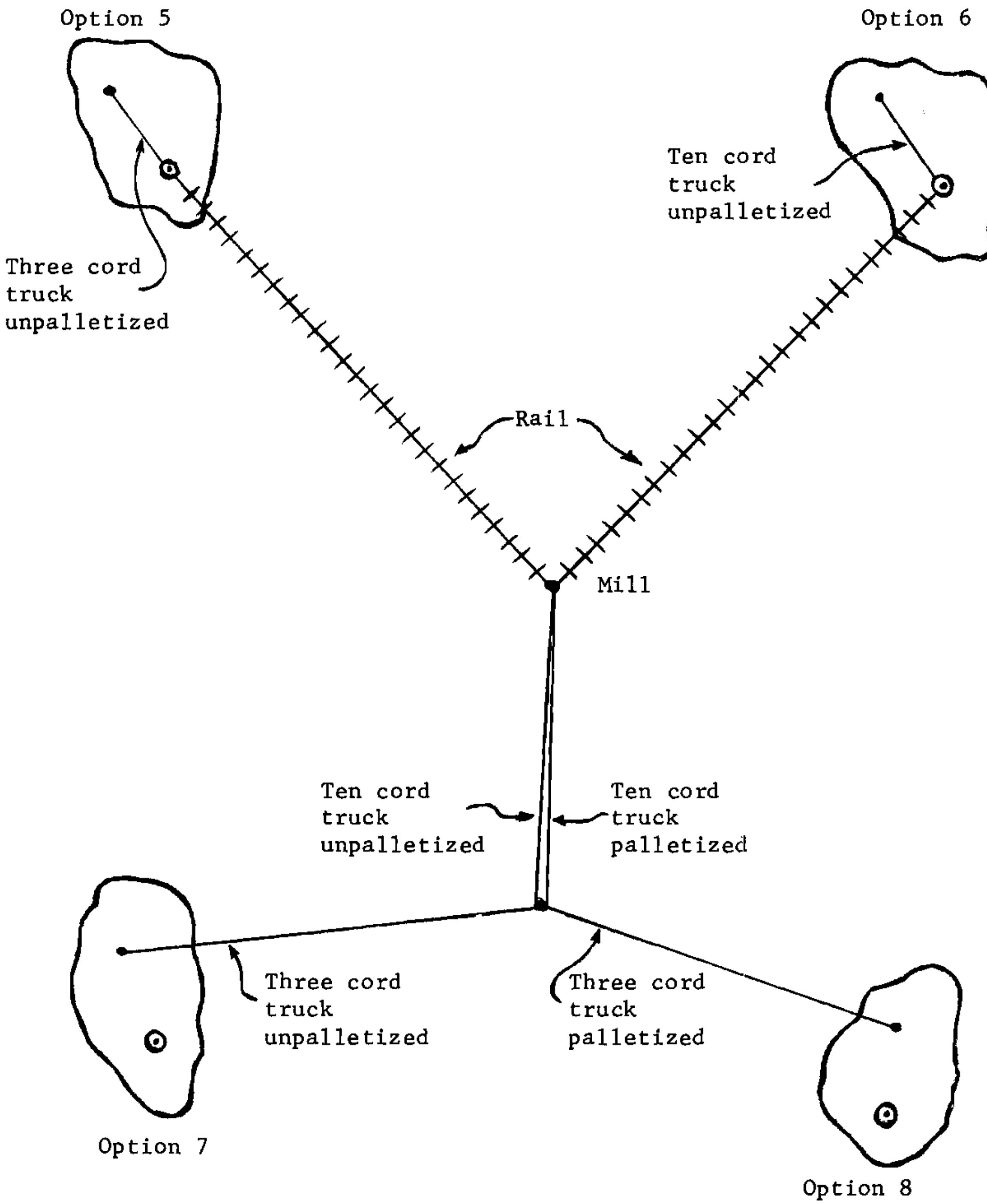

Figure 3. Transportation Options 5 through 8

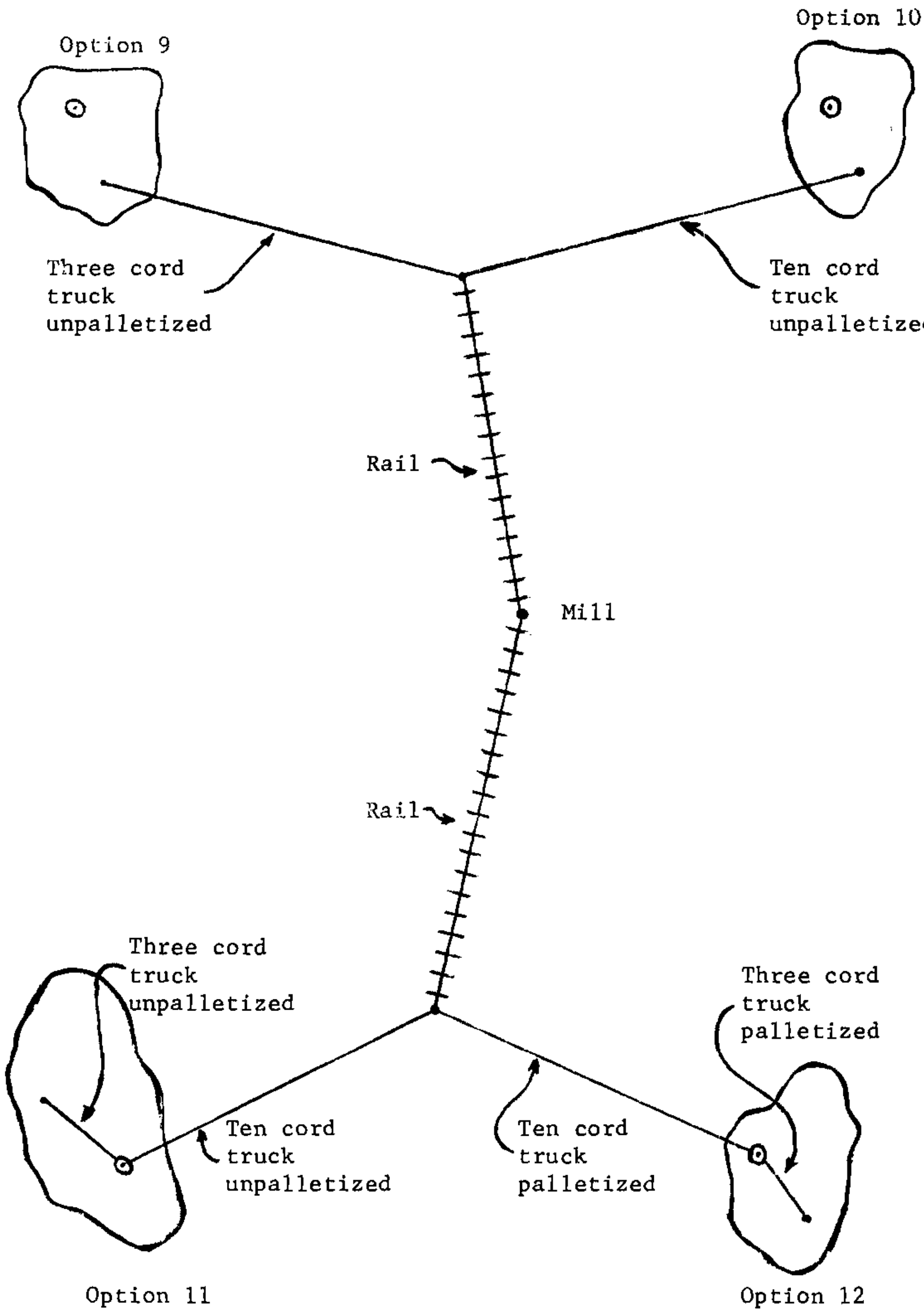

Figure 4. Transportation Options 9 through 12

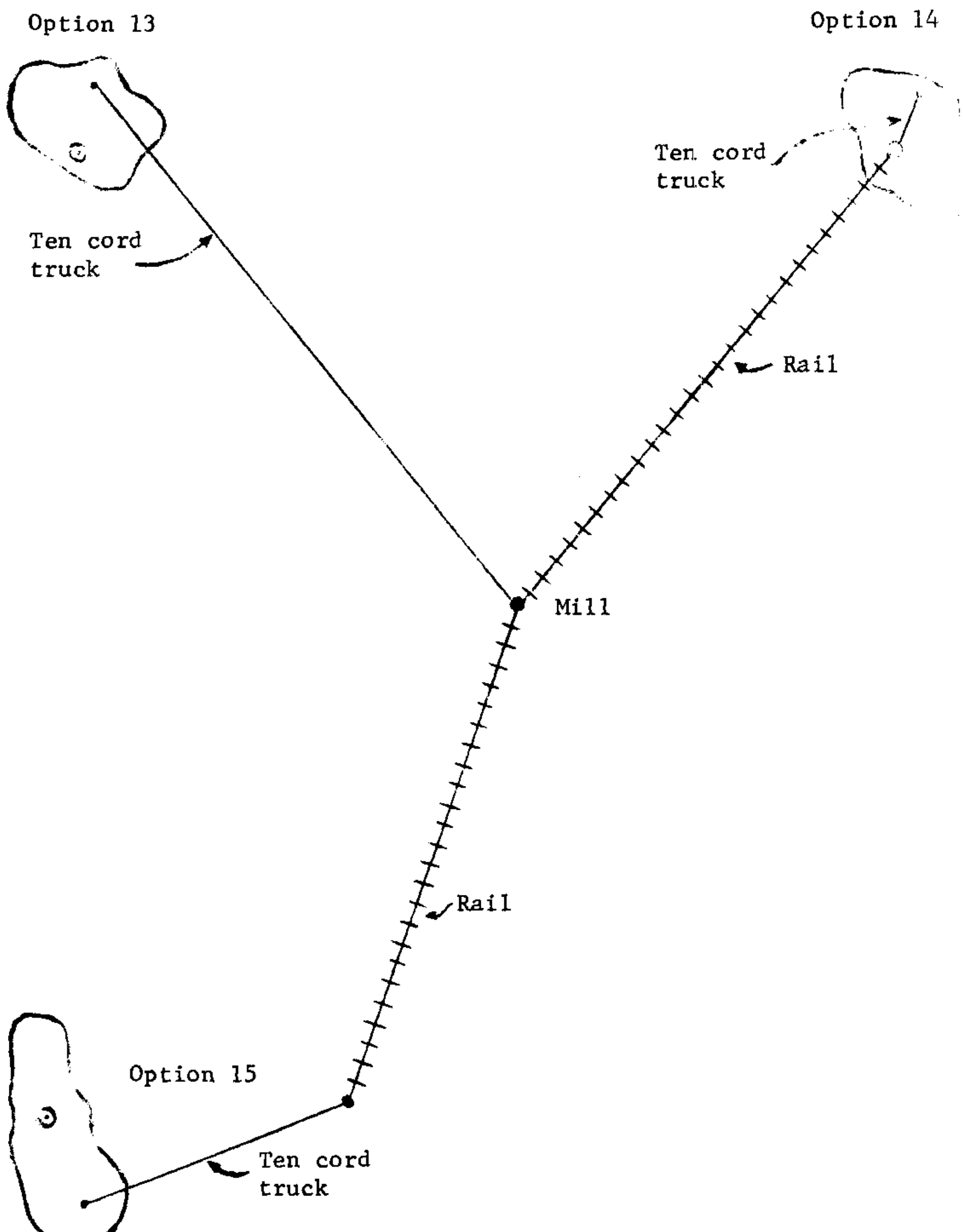

Figure 5. Transportation Options 13 through 15

General Linear Programming Approach

Another method of solving the pulpwood transportation problem would be through the use of linear programming. Given the harvesting areas, dealer locations, and mill location as shown in Figure 1, formula 2 describes an objective function which could be used.

$$
\begin{aligned}
\text{MIN } Z = & \sum_{k_1} \sum_{m} \sum_{n} C(a_{mn}, f_n)_{k_1} \; V(a_{mn}, f_n)_{k_1} \\
& + \sum_{k_2} \sum_{n} C(f_n, d_1)_{k_2} \; V(n_f, d_1)_{k_2} \\
& + \sum_{k_3} \sum_{n} (f_n, b_n)_{k_3} \; V(f_n, b_n)_{k_3} \\
& + \sum_{k_4} \sum_{n} C(b_n, d_1)_{k_4} \; V(b_n, d_1)_{k_4} \\
& + \sum_{k_5} \sum_{m} \sum_{n} C(a_{mn}, d_1)_{k_5} \; V(a_{mn}, d_1)_{k_5} \\
& + \sum_{k_6} \sum_{m} \sum_{n} C(a_{mn}, b_n)_{k_6} \; V(a_{mn}, b_n)_{k_6}
\end{aligned} \tag{2}
$$

The six components of formula 2 represent the costs associated with the six transportation arcs: forest landing to forest dealer, forest dealer to mill, forest dealer to between-forest dealer, between-forest dealer to mill, forest landing to mill, and forest landing to between-forest dealer respectively.

Where

A = Set of forest landings a_{11}, a_{21}, a_{31}, ...a_{mn}.

m = Landing number

n = Forest number

B = Set of between-forest dealers b_1, b_2, b_3,...b_n.

D = Set of destinations d_1.

F = Set of forest dealers f_1, f_2, f_3,...f_n.

k = Set of transportation alternatives for each arc k_1, k_2, k_3,...k_p.

$C(i,j)_{k_p}$ = Cost of shipping one cord of wood from location i to location j by method k_p.

$V(i,j)_{k_p}$ = Volume, in cords of wood shipped from location i to location j by method k_p.

The following equations represent the constraint equations which would be used. Formula 3 represents the demand constraint where W is the total demand for wood at the mill.

$$\sum_{k_1} \sum_m \sum_n V(a_{mn}, f_n)_{k_1} + \sum_{k_5} \sum_m \sum_n V(a_{mn}, d_1)_{k_5} + \sum_{k_6} \sum_m \sum_n V(a_{mn}, b_n)_{k_6} \geq W \quad (3)$$

Formulas 4 and 5 represent inventory constraints on the between-forest dealers and the forest dealers. These equations insure that all wood moved into these dealers is also moved out and the inventory at these intermediate dealers remains at zero.

$$\omega^+(B) = \omega^-(B) \quad (4)$$

$$\omega^+(F) = \omega^-(B) \quad (5)$$

Formula 6 represents the volume constraint on each of the forest landings where S_{mn} is the maximum volume of wood that can be shipped from landing a_{mn}.

$$V(a_{mn}) \quad S_{mn} \tag{6}$$

A constraint equation may also be used to reflect limitations on the amount of wood that can be shipped by any specific method.

While the preceeding linear programming approach could be used to solve the pulpwood transportation problem it was rejected in favor of an iterative method for the following reasons:

(1) The linear programming model assumes that the cost of transportation varies as a linear function with volume. This assumption is not necessarily true in terms of vehicle write-off costs, consumable costs or labor rates. The iterative method allows the use of step functions and other non-linear relationships.

(2) It is difficult to get sub-optimal results using linear programming techniques. Linear programming method generally only yields optimal results. By using an iterative technique, it is possible to get the cost of all methods of transportation between the given points. This allows for comparison of transportation methods between points while taking into account cost considerations that may not have been included in the model.

CHAPTER IV

DESCRIPTION OF THE MODEL

General Description

The computer model is presented and briefly explained in this chapter. It is assumed that the reader has some knowledge of Extended ALGOL including the use of procedures. Only the more important procedures will be explained in detail. A complete computer program may be found in Appendix B. Definitions of the identifiers used in the program may be found in Appendix A.

The computer model consists of nine procedures which are used to print output, compute distances and compute costs, and a program section which is the driving force of the model. The program accepts the data in free field form.

The first section of input cards contains data concerning mill and forest locations. The first card in this section denotes the number of forests to be considered (NAREA). For example, this data card could appear as: 4,

The second set of cards in this section contains one card for each of the NAREA forests, containing the following data:

(1) Distance to forest dealer I from the mill (FMDIST [I]).

(2) Compass heading from the mill to forest dealer I (FMRAD [I]).

(3) Number of landings in forest I (NLAND [I]).

(4) Distance from forest dealer to landing IJ (DLDIST [I,J]).

(5) Compass heading from forest dealer to landing IJ (DLRAD [I,J]).

The following is an example of the type of data card that could be used in this part of the section:

123, 90, 3, 23, 100, 16, 175, 22, 270,

(1) (2) (3) (4) (5) (4) (5) (4) (5)

The second section of cards contains the data concerning the between-forest truck dealers. The first card in this section denotes the number of between-forest truck dealers to be considered (NTPUP). For example, this data card could appear as:

2,

The second set of cards in this section contains one card for each of the NTPUP between-forest truck dealers with the following information:

(1) Distance from the mill to truck dealer K (TMDIST [K]).

(2) Compass heading from the mill to truck dealer K (TMRAD [K]).

(3) Number of forests served by truck dealer K (NFTPUP [K]).

(4) Forests served by truck dealer K (FTPUP [K,L]).

The following is an example of the type of data card that could be used in this part of the section:

144, 120, 2, 1, 2,

(1) (2) (3) (4) (4)

The third section of cards contains the data concerning the between-forest rail dealers. The first card in this section denotes the number of between-forest rail dealers to be considered (NRPUP). For example, this card could appear as:

2,

The second set of cards in this section contains one card for each of the NRPUP between-forest rail dealers with the following information:

(1) Distance from the mill to rail dealer M (RMDIST[M]).

(2) Compass heading from the mill to rail dealer M (RMRAD [M]).

(3) Number of forests served by rail dealer M (NFRPUP [M]).

(4) Forests served by the rail dealer M (FRPUP [M,N]).

The following is an example of the type of data card that could be used in this section:

11, 33, 3, 2, 3, 4,

(1) (2) (3)(4) (4) (4)

Table 1 shows the current maximum number of each variable that will be accepted by the computer model. The maximum number for any item may be increased by increasing the applicable array size.

After accepting the input data, the program iterates through each forest landing and computes the cost of transportation for each of the 15 options previously listed. These computations are accomplished by the use of procedure calls and calculations as listed in the PROGRAM section of the computer program. The remainder of this chapter is concerned with a more detailed explanation of the procedures used.

Specific Procedures

Heading Procedure

This procedure prints out the first two pages of output as shown in Appendix C. These are the title page and the listing of transportation options to be considered.

Initialize Procedure

The first part of this procedure establishes the cost, in cents per cord, for the loading, unloading, transfer and bucking operations. The second part of the procedure sets up a series of switches to be used in later procedures to determine which forests are served by the between-forest truck and rail dealers.

Table 1. Current Variable Capacity

Item	Capacity
Number of Forests	4
Number of Landings per Forest	6
Number of Between-Forest Truck Dealers	4
Number of Between-Forest Rail Dealers	4
Number of Forests That Can be Served by any Between-Forest Truck Dealer	4
Number of Forests that Can be Served by any Between-Forest Rail Dealer	4
Number of Transportation Options Considered for Each Landing	15

Distance Procedure

The Distance procedure is used to compute the distance between two points in the area under consideration, neither of which is a forest landing. The distance is computed by using elementary trigonometric operations.

Gdistance Procedure

The Gdistance procedure is used to compute the distance between two points in the area under consideration, one of which is a forest landing. As with the Distance procedure, the Gdistance is computed using elementary trigonometric operations.

Truckrate Procedure

This procedure is used to compute the hauling cost per cord for transporting wood by a specific truck size over a given distance. The formal parameter of this procedure, named Trucktype, determines which type of truck is to be considered. The type of truck used in the procedure depends on truck capacity, whether or not pallets are used, and the velocities that the truck will be traveling. The following types of trucks are considered:

(1) Three cord unpalletized truck carrying shortwood, which starts

at the forest landing and goes through all three speeds: V1, V2, and V3.

(2) Ten cord unpalletized truck carrying shortwood, which starts at the forest landing and goes through all three speeds: V1, V2, and V3.

(3) Three cord unpalletized truck carrying shortwood, which starts at the forest landing and goes to the forest dealer. This truck uses two speeds: V1 and V2.

(4) Ten cord unpalletized truck carrying shortwood, which starts at the forest dealer and goes through speeds V2 and V3. This type of truck may deliver wood to the mill or a between-forest rail dealer.

(5) Three cord palletized truck carrying shortwood, which starts at the forest landing and goes to the forest dealer. This truck uses two speeds: V1 and V2.

(6) Ten cord palletized truck carrying shortwood, which starts at the forest dealer and goes through speeds V2 and V3. This type of truck may deliver wood to the mill or a between-forest rail dealer.

(7) Ten cord unpalletized truck carrying shortwood, which starts at the forest landing and goes to the forest dealer. This type of truck uses two speeds: V1 and V2.

(8) Ten cord unpalletized truck carrying shortwood, which starts at the between-forest truck dealer and goes to the mill. This truck only uses speed V3.

(9) Three cord palletized truck carrying shortwood, which starts at the forest landing and goes through all three speeds, V1, V2, and V3. This type of truck may deliver wood to the mill or a between-forest truck dealer.

(10) Ten cord palletized truck carrying shortwood, which starts at a between-forest truck dealer and goes to the mill. This truck only uses

speed V3.

(11) Ten cord unpalletized truck carrying longwood, which starts at the forest landing and goes through all three speeds: V1, V2, and V3.

(12) Ten cord unpalletized truck carrying longwood, which starts at the forest landing and goes to the forest dealer. This truck uses speeds V1 and V2.

The designation of a specific type of truck on a given pass through the Truckrate procedure determines the following variables about the truck:

CAP--The truck capacity in cords.

TUL--The time to load and unload the truck, in hours.

WROFF--The write-off cost per day on the truck, in cents.

MAINT--The maintenance cost per day on the truck, in cents.

CONS--The cost of consumables such as gasoline and oil per hour, in cents. The cost of consumables is taken to vary with time and not by the various speeds used by the trucks. At lower speeds on unimproved roads, the trucks would be using lower gears than on the open roads. This will result in approximately the same amount of gasoline and oil consumption per hour, regardless of the speed used.

PALL--The cost per trip of pallets (if used), in cents.

R1--The round trip distance traveled at speed V1.

R2--The round trip distance traveled at speed V2.

R3--The round trip distance traveled at speed V3.

If the one way distance traveled is less than 20 miles the volume carried by the truck is multiplied by 1.2. This gives an overload factor of 20 percent for short hauling distances.

The Truckrate procedure then uses formula 7 to compute the basic number of round trips per day the truck can make over the given distance.

$$RT = \frac{T-TN}{TUL+R1/V1+R2/V2+R3/V3} \tag{7}$$

Where

RT = The number of round trips per day.

T = Total time available per day in hours.

TN = Time for non-work per day for the truck in hours (idle time).

TUL = Time to load and unload the truck.

R1 = Round trip distance at speed V1.

V1 = Speed of the truck on unimproved forest roads.

R2 = Round trip distance at speed V2.

V2 = Speed of the truck on improved forest roads.

R3 = Round trip distance at speed V3.

V3 = Speed of the truck on the open road.

The number of round trips per day is then converted to the nearest integer or integer + 0.5 by use of the ENTIER function. This is done to reflect the fact that the truck should end the day either at the mill or at the forest landing. If the truck ends the day at any location between the forest landing and the mill the remainder of the half round trip transportation costs are assumed to be an employee transportation benefit.

The total operating time per round trip haul (OT) is then calculated by the use of formula 8.

$$OT = R1/V1+R2/V2+R3/V3 \tag{8}$$

From the preceeding calculations, the total cost per truck for hauling one load of wood is computed using formula 9.

$$CPT = LPH\times(OT+TUL+TN/RT)+\frac{WROFF+MAINT+PALL}{RT+CONS\times OT}$$

Where

CPT = Cost for transporting one truckload of wood, in cents.

LPH = Labor cost per hour, in cents.

OT = Truck operating time, round trip, for one load of wood, in hours.

TUL = Time to load and unload the truck, in hours.

TN = Time for non-work per day, in hours

RT = Adjusted number of round trips per day for one truck.

WROFF = The write-off cost per day on the truck, in cents.

MAINT = The maintenance cost per day on the truck, in cents.

PALL = The cost per trip of pallets (if used), in cents.

CONS = The cost of consumables such as gasoline and oil per hour, in cents.

The final calculation of this procedure converts the cost per truck to a cost per cord (TCOST) for the haul by formula 10.

$$TCOST = CTP/VOL \tag{10}$$

Where

VOL = Volume of wood carried by the truck, in cords, adjusted for an overload factor, if applicable.

<u>Railrate Procedure</u>

This procedure determines the cost per cord of hauling shortwood by rail. It is a table look-up procedure that compares an input distance value with values listed in the table. When a table value is found which is equal to or greater than the input distance value, the corresponding cost is the output. Standard railroad transportation costs are used, based on Interstate Commerce Commission tariffs.

Optimize Procedure

The Optimize procedure is used to determine the minimum cost option of each landing studied for shipping wood from that landing. The procedure first sets MINCOST [I,J] to an arbitrarily large number. The procedure then iterates through the 15 computed costs and, each time a cost is found which is less than MINCOST [I,J], that cost replaces MINCOST [I,J]. The resulting output is the minimum cost and its associated option.

Optimizes Procedure

This procedure operates the same as the Optimize procedure except that only the first 12 options are considered. The resulting output is the minimum cost shortwood option and its associated option number.

Output Procedure

This procedure generates the program output as shown in Appendix C with the exception of the first two pages which were generated by the Heading procedure.

The first section of output printed by this procedure gives the general information concerning the mill, forest landing, and between-forest dealers. This general information includes the number of forests and landings to be considered, the number of between-forest dealers, and data on distance and location of these facilities from the mill.

The second section of output deals with cost options for the various forest landings. Each forest landing is listed along with the cost of shipping wood from that landing to the mill by each of the 15 options previously described.

The third and fourth sections of output each present the least cost options from each landing. The third section considers all of the options presented while the fourth section only considers shortwood options.

CHAPTER V

DESIGN AND RESULTS OF EXPERIMENTS

Introduction

To satisfy the objectives of this investigation, four experiments were performed using the computer model. The purpose of these experiments was to determine how the least cost options would change when the distances between various locations were varied. The distance parameters which were varied are:

(1) Distance from the forest landing to the forest dealer.

(2) Distance from the forest dealer to the between-forest rail and truck dealers.

(3) Distance from the between-forest rail and truck dealers to the mill.

The cost data used in these experiments are hypothetical and not intended to represent any particular pulpwood mill situation. An attempt has been made to keep all data realistic, and the values used could be realized by the use of existing equipment. The use of this model by a particular organization would require that organization to insert its own cost data.

Derivation of Data

Truck Hauling Costs

The write-off costs for the trucks were calculated using formula 11 (13). Maintenance costs for the three cord truck was assumed to be 100 percent of the write-off cost while maintenance costs for the ten cord truck was assumed to be 50 percent of the write-off cost.

$$WROFF = \frac{(C-L)(CRF)+LxP}{D} \tag{11}$$

Where

WROFF = Write-off cost per day

C = Initial value of the equipment

L = Salvage value of the equipment

CRF = Capital recovery factor for the specified write-off period.

P = Percentage used in the Capital Recovery Factor.

D = Number of days equipment is available per year.

250 working days per year
-5 percent for maintenance
-5 percent for bad weather
D = 225 available days per year

Three Cord Truck

Initial Value = \$4,000

Salvage Value = \$1,000

Write-off Period = 4 years

$$WROFF = \frac{(C-L)(CRF @ 7\%, 4 \text{ yrs.})+LxP}{D}$$

$$= \frac{(4000-1000)(.295)+(1000)(.07)}{225}$$

$$= \$4.25/\text{day}$$

Maintenance cost = 100 percent of write-off cost

= \$4.25/day

Ten Cord Truck

Initial Value = \$15,000

Salvage Value = \$ 3,000

Write-off Period = 4 years

$$\text{WROFF} = \frac{(\text{C-L})(\text{CRF @ 7\%, 4 yrs.})+\text{LxP}}{\text{D}}$$

$$= \frac{(15{,}000-3000)(.295)+(3000)(.07)}{\text{D}}$$

$$= \$16.75/\text{day}$$

Maintenance Cost = 50 percent of write-off cost

= $8.38/day

A one shift operation of the transportation system was assumed for these experiments which yielded T equal to eight hours. The truck idle time for refueling, servicing, lunch and coffee breaks, (TN) was assumed to be one hour per day. A labor cost of $2.00 per hour was used in the calculations (LPH = 200 cents per hour).

Table 2 shows the times, in hours, that were used as load-unload times for the various sizes and configurations of vehicles. The times shown represent the total time spent by a vehicle in the loading and unloading function. Table 3 shows the truck capacities. Pallets are assumed to reduce truck capacity by one fourth of a cord for every three cords in the original truck capacity.

Cost of using Pallets

Initial Value = $250

Salvage Value = $ 25

Write-off Period = 4 years

Using the same formula as was used to determine the vehicle write-off cost and multiplying by a factor of 1.5 to account for maintenance costs:

$$\text{WROFF} = \left[\frac{(\text{C-L})(\text{CRF @ 7\%, 4 yrs.})+\text{LxP}}{\text{D}}\right] \text{x}1.5$$

$$= \left[\frac{(250-25)(.295)+(25)(.07)}{225}\right] \text{x}1.5$$

$$= \$0.449/\text{day}$$

Table 2. Vehicle Load-Unload Times (Hours)

Type of Vehicle	Unpalletized	Palletized
Three Cord Truck (Shortwood)	1.5	0.5
Ten Cord Truck (Shortwood)	5.0	1.63
Ten Cord Truck (Longwood)	3.33	N/A

Table 3. Truck Capacities

Truck Size	Wood Type	Pallets	Capacity (Cords)
Three Cord	Shortwood	No	3
Three Cord	Shortwood	Yes	2.75
Ten Cord	Shortwood	No	10
Ten Cord	Shortwood	Yes	9.25
Ten Cord	Longwood	No	10

Each three cord truck will require three pallets in the system to account for those on the truck, those in maintenance, and those off the trucks either in forest being loaded or at a dealer being unloaded. The ten cord truck will require eight pallets in the system.

Three Cord Truck	Ten Cord Truck
\$0.449	\$0.449
x3	x8
\$1.345/day	\$3.58/day

Cost of Consumables. The following table shows the miles per gallon and the cost of fuel per gallon for the three cord and the ten cord trucks. The three cord truck is assumed to be powered by gasoline and the ten cord truck by diesel fuel.

Table 4. Fuel Data

	Three Cord Truck	Ten Cord Truck
Miles per gallon	7	10
Cents per gallon	24	16

The following calculations compute the cost per hour, including an additional eight percent for lubrication, at a speed of 45 miles per hour. It is assumed that the same cost per hour will be valid at lower speeds in the forest area since the truck will be on unimproved roads and using lower gears.

Three Cord Truck

$\frac{24}{7} =$ 3.42 cents/mile
x1.08
3.7 cents/mile
x 45 mph
166.5 cents/hour

Ten Cord Truck

$\frac{16}{10} =$ 1.6 cents/mile
x1.08
1.73 cents/mile
x 45 mph
77 cents/hour

Constants and Experimental Variables

Table 5 shows the value of the remaining constants used. For the computations of R1, R2 and R3 in Table 5, the distance from the forest landing to the forest road is taken to be two miles thus R1, being the round trip distance, equals four miles. The distance traveled on improved roads within the forest is a maximum of 40 miles for the round trip.

Each of the four experiments performed contained four forest areas, two between-forest rail dealers and two between-forest truck dealers. The following distances were varied by the amounts indicated:

(1) The distance from the forest landing to the forest dealer, five to 20 miles, varied in five mile increments.

(2) The distance from the forest dealer to the between-forest rail and truck dealers, 20 to 50 miles, varied in ten mile increments.

(3) The distance from the between-forest rail and truck dealers, 50 to 200 miles, varied in 50 mile increments. The data for the four experiments are shown in Tables 6 through 13.

Results of Experiments

The results discussed in this section are valied only for the hypothetical situations described and not for any specific mill, since the cost data used is representative of typical systems, but not particular to any one mill. Tables 14 through 17 summarize the findings of the four experiments, showing the least cost option when all transportation options are considered and the least cost option when only shortwood

Table 5. Constants Used in Experiments

Constant	Cost in Cents	Distance in Miles	Speed in Miles Per Hour
BTLOAD	437		
PBTLOAD	450		
TCLOAD	437		
PTCLOAD	450		
BTUNLOAD	70		
PBTUNLOAD	70		
TCUNLOAD	70		
PTCUNLOAD	70		
BTTCTRANS	70		
PBTTCTRANS	70		
BTRRTRANS	70		
PBTRRTRANS	70		
TCRRTRANS	70		
PTCRRTRANS	70		
WSAW	180		
DSAW	90		
MSAW	50		
RRUNLOAD	70		
LLOAD	360		
LUNLOAD	70		
R1		4	
R2		$4 < R2 \leq 44$	
R3		$44 < R3$	
V1			5
V2			15
V3			45

Table 6. Forest Data for Experiment One

Forest Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Landing Number	Distance from Forest Dealer in Miles	Compass Heading from Forest Dealer in Degrees
1	91.00	27.00	1	20.00	0.00
			2	15.00	45.00
			3	5.00	270.00
			4	10.00	315.00
2	75.00	163.00	1	5.00	90.00
			2	10.00	135.00
			3	15.00	154.00
			4	20.00	196.00
3	65.00	192.00	1	5.00	135.00
			2	20.00	180.00
			3	15.00	225.00
			4	10.00	270.00
4	84.00	318.00	1	15.00	0.00
			2	20.00	47.00
			3	5.00	270.00
			4	10.00	315.00

Table 7. Between-Forest Dealer Data for Experiment One

Truck Dealer Number	Rail Dealer Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Forests Served
1		50.00	0.00	1,4
2		50.00	180.00	2,3
	1	50.00	0.00	1,4
	2	50.00	180.00	2,3

Table 8. Forest Data for Experiment Two

Forest Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Landing Number	Distance from Forest Dealer in Miles	Compass Heading from Forest Dealer in Degrees
1	136.00	17.00	1	20.00	0.00
			2	15.00	45.00
			3	5.00	270.00
			4	10.00	315.00
2	124.00	170.00	1	5.00	90.00
			2	10.00	135.00
			3	15.00	154.00
			4	20.00	196.00
3	115.00	187.00	1	5.00	135.00
			2	20.00	180.00
			3	15.00	225.00
			4	10.00	270.00
4	133.00	348.00	1	15.00	0.00
			2	20.00	47.00
			3	5.00	270.00
			4	10.00	315.00

Table 9. Between-Forest Dealer Data for Experiment Two

Truck Dealer Number	Rail Dealer Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Forests Served
1		100.00	0.00	1,4
2		100.00	180.00	2,3
	1	100.00	0.00	1,4
	2	100.00	180.00	2,3

Table 10. Forest Data for Experiment Three

Forest Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Landing Number	Distance from Forest Dealer in Miles	Compass Heading from Forest Dealer in Degrees
1	190.00	13.00	1	20.00	0.00
			2	15.00	45.00
			3	5.00	270.00
			4	10.00	315.00
2	170.00	173.50	1	5.00	90.00
			2	10.00	135.00
			3	15.00	154.00
			4	20.00	196.00
3	166.00	185.50	1	5.00	135.00
			2	20.00	180.00
			3	15.00	225.00
			4	10.00	270.00
4	180.00	351.00	1	15.00	0.00
			2	20.00	47.00
			3	5.00	270.00
			4	10.00	315.00

Table 11. Between-Forest Dealer Data for Experiment Three

Truck Dealer Number	Rail Dealer Number	Distance from Mill in Miles	Compass Heading from Mill in Miles	Forests Served
1		150.00	0.00	1,4
2		150.00	180.00	2,3
	1	150.00	0.00	1,4
	2	150.00	180.00	2,3

Table 12. Forest Data for Experiment Four

Forest Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Landing Number	Distance from Forest Dealer in Miles	Compass Heading from Forest Dealer in Degrees
1	235.00	10.00	1	20.00	0.00
			2	15.00	45.00
			3	5.00	270.00
			4	10,00	315.00
2	225.00	174.60	1	5.00	90.00
			2	10.00	135.00
			3	15.00	154.00
			4	20.00	196.00
3	216.00	184.00	1	5.00	135.00
			2	20.00	180.00
			3	15.00	225.00
			4	10.00	270.00
4	231.00	354.00	1	15.00	0.00
			2	20.00	47,00
			3	5.00	270.00
			4	10.00	315.00

Table 13. Between-Forest Dealer Data for Experiment Four

Truck Dealer Number	Rail Dealer Number	Distance from Mill in Miles	Compass Heading from Mill in Degrees	Forests Served
1		200.00	0.00	1,4
2		200.00	180.00	2,3
	1	200.00	0.00	1,4
	2	200.00	180.00	2,3

Table 14. Results of Experiment One

Forest Number	Landing Number	Least Cost Option	Cost of Option in Cents/Cord	Least Cost Shortwood Option	Cost of Option in Cents/Cord
1	1	13	1309.16	6	1510.41
	2	14	1299.30	6	1494.70
	3	14	1191.00	5	1441.53
	4	14	1206.70	6	1479.00
2	1	13	991.39	5	1411.25
	2	14	1176.42	6	1448.72
	3	14	1269.02	6	1464.42
	4	14	1284.72	6	1480.13
3	1	13	980.38	5	1380.97
	2	14	1254.44	6	1449.85
	3	13	993.14	6	1434.14
	4	13	980.30	6	1418.44
4	1	14	1269.02	6	1464.42
	2	13	1280.88	6	1480.13
	3	14	1160.72	5	1411.25
	4	14	1176.42	6	1448.72

Table 15. Results of Experiment Two

Forest Number	Landing Number	Least Cost Option	Cost of Option in Cents/Cord	Least Cost Shortwood Option	Cost of Option in Cents/Cord
1	1	13	1367.00	6	1568.81
	2	14	1357.70	6	1553.10
	3	14	1249.40	5	1499.93
	4	14	1265.10	6	1537.40
2	1	14	1221.28	5	1471.81
	2	14	1236.98	6	1509.28
	3	14	1329.58	6	1524.98
	4	14	1345.28	6	1540.69
3	1	14	1221.28	5	1471.81
	2	13	1341.41	6	1540.69
	3	14	1329.58	6	1524.98
	4	14	1236.98	6	1509.28
4	1	13	1357.53	6	1553.10
	2	13	1353.29	6	1568.81
	3	14	1249.40	5	1499.93
	4	14	1265.10	6	1537.40

Table 16. Results of Experiment Three

Forest Number	Landing Number	Least Cost Option	Cost of Option in Cents/Cord	Least Cost Shortwood Option	Cost of Option in Cents/Cord
1	1	13	1435.21	6	1631.54
	2	14	1420.43	6	1615.83
	3	14	1312.13	5	1562.66
	4	14	1327.83	6	1600.13
2	1	14	1279.69	5	1530.22
	2	14	1295.39	6	1567.69
	3	14	1387.99	6	1583.39
	4	14	1403.69	6	1599.10
3	1	14	1279.69	5	1530.22
	2	14	1403.69	6	1599.10
	3	14	1387.99	6	1583.39
	4	14	1295.39	6	1567.69
4	1	13	1416.73	6	1615.83
	2	13	1413.06	6	1631.54
	3	14	1312.13	5	1562.66
	4	14	1327.83	6	1600.13

Table 17. Results of Experiment Four

Forest Number	Landing Number	Least Cost Option	Cost of Option in Cents/Cord	Least Cost Shortwood Option	Cost of Option in Cents/Cord
1	1	13	1491.97	6	1722.39
	2	13	1482.82	6	1706.68
	3	14	1402.98	5	1653.51
	4	14	1418.68	6	1690.98
2	1	14	1371.61	5	1622.14
	2	14	1387.31	6	1659.61
	3	13	1472.36	6	1675.31
	4	13	1478.15	6	1691.02
3	1	14	1371.61	5	1622.14
	2	13	1468.40	6	1691.02
	3	13	1457.82	6	1675.31
	4	14	1387.31	6	1659.61
4	1	13	1480.92	6	1706.68
	2	13	1477.95	2	1719.03
	3	14	1402.98	5	1653.51
	4	14	1418.68	6	1690.98

transportation options are considered.

Minimum Option

When all transportation methods are considered in the four experiments, option 13 or 14 is chosen as the minimum cost in every case. Option 13 is shipment of longwood directly from the forest landing to the mill by ten cord truck. Option 14 is shipment of longwood from the forest landing to the forest dealer by ten cord truck and from the forest dealer to the mill by rail. Option 14 is chosen over option 13 unless the distances and angle formed by the forest landing to forest dealer to mill route combine in such a way as to make option 13 more economical. In general, the following situations will cause the minimum option to change from 14 to 13:

(1) Increasing the angle formed by the forest landing to forest dealer to mill route.

(2) Increasing the distance between the forest dealer and the mill.

(3) Increasing the distance from the forest landing to the forest dealer.

Minimum Shortwood Option

When only shortwood transportation methods are considered in the four experiments, options 2, 5 and 6 are chosen as the minimum costs. Option 2 is shipment of unpalletized shortwood from the forest landing to the mill by ten cord truck. Option 5 is shipment of unpalletized shortwood from the forest landing to the forest dealer by three cord truck and from the forest dealer to the mill by rail. Option 6 is shipment of unpalletized shortwood from the forest landing to the forest dealer by ten cord truck and from the forest dealer to the mill by rail.

Option 2 appears as the minimum cost option only once in the four experiments. This case appears in experiment four where the distance and angle formed by the forest landing to forest dealer to mill route combine to make direct shipment to the mill by truck more economical.

Other than the case mentioned above, option 6 is shown to be more economical than option 5 except in those cases where the distance from the forest landing to the forest dealer is five miles. Shortwood options seem to be less effected by the distance from the forest dealer to the mill and the angle formed by the forest landing to forest dealer to mill route than when all the options were considered.

CHAPTER VI

USE OF THE MODEL

General Comments

The model derived in this investigation is designed for use in the pulpwood industry as an aid in determining the most economical method of transporting wood from the forest landing to the mill. Any organization using the model must supply cost data particular to that individual mill in order that they may study their specific situation and not an average system as was done in this investigation. Additional options may be added by expanding the PROGRAM section and the procedures.

Impact of the Current Situation

The model computes the most economical transportation costs without regard to the current transportation system being employed and the investment in current equipment. An organization using the model must take these factors into account when making the decision as to whether or not to change their transportation system based on the model output. It may be that the cost of converting to a new transportation system would be more than the savings realized by the conversion.

Changes in the System Over Time

No transportation system is static. That is, the variables input to the model will change over time. Distances from point to point will change as forest areas are expanded or increased in number, cost factors will change, and new transportation equipment and methods will be developed.

This means that the model cannot be run once and the answer derived expected to be valid over a long period of time. A mill using this model may either run the model again as the situation changes or attempt to predict what changes will take place and run the model in an attempt to optimize future situations. When considering future changes, the model would become a simulation tool which could be used to determine the sensitivity of the transportation costs to certain parameters such as the distance between various points within the system.

Volume Considerations

The volume of wood being shipped was not considered in this model. The model assumes only that there is a sufficient volume of wood at any point to warrant shipment by any of the options listed and that there are enough vehicles of the types used to transport any amount of wood generated. These assumptions may not be valid for every situation. Terrain conditions may be such that ten cord trucks cannot reach certain landings. Rail dealers may have a certain volume beyond which they cannot handle due to car limitation. The model user must be aware of conditions such as these that may exist in a particular situation and take them into account when interpreting the model results.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

General

The nature of the results derived from the experiments indicated that the computer model performed as expected and provided data in a useable form. The results obtained from these experiments are valid only for the general situation described. Use of this model by a mill requires that the mill supply its own cost data.

The model presented does not take into account forms of pulpwood transportation such as a barge or pipeline. Also, only two sizes of trucks were studied. The conclusions should be read in the light of these factors.

Conclusions

(1) The model developed in this investigation appears to be a realistic model for studying pulpwood transportation systems of a mill. The model is flexible and can be easily adaptable to additional transportation options.

(2) Extended ALGOL is an appropriate language for modeling this type of system. The ease of programming, the speed of computation, and the use of procedures are some of the language's assets.

(3) An examination of the applicable literature indicates that little attention has been paid to optimizing transportation costs by the mills. Since the majority of the mill's wood is bought from independent producers or dealers, they tend to regard the transportation system only

as a service to be purchased. Trends indicate that, in the future, mills may own or lease more land from which to harvest wood rather than buying wood from producers or dealers. As this trend develops, mills should become more concerned with finding the least cost transportation system.

(4) There is no general solution to the problem of which type of pulpwood transportation is most economical. Each situation must be studied independently, using costs particular to that situation, to find the most economical transportation alternatives.

(5) Previous attempts to analyze pulpwood transportation systems relied on average costs per mile, disregarding the fact that there are fixed and variable costs that do not vary linearly with distance.

(6) In the system studied, longwood transportation systems were shown to be the most economical, either directly to the mill by truck or via a rail dealer on a ten cord truck, then to the mill by rail in shortwood form. Of the shortwood systems studied, the rail options were generally the most economical.

Recommendations

(1) The study should be expanded to include other transportation modes such as barge, pipeline or additional truck sizes. More realistic results could be obtained with additional options considered.

(2) The transportation system should be expanded to include wood movement from the stump to the landing. This would involve a sub-model which optimizes the delivery system between the stump and the landing or by-passes the landing and delivers wood from the stump to another point within the system.

(3) The model should be extended to take into consideration volume as a variable such as:

•

(a) Mill capacity

(b) Forest capacity

(c) Rail and truck dealer capacity

(4) Further study is recommended into the area of changing from one transportation system to another. The model could be expanded to accept as input the current transportation system being used, and produce an output relating to the cost of changing the system.

APPENDIX A

PROGRAM TERMINOLOGY

BDEG	=	Formal parameter of the GDISTANCE procedure denoting the compass heading from the mill to the point under consideration which is not the landing.
BDIST	=	Formal parameter of the GDISTANCE procedure denoting the distance from the mill to the point under consideration which is not the landing.
BMH	=	Computed cost from between area dealer to mill.
BTLOAD	=	Cost of loading one cord of shortwood on three cord truck.
BTRRTRANS	=	Cost of transferring one cord of shortwood from three cord truck to rail car.
BTTCTRANS	=	Cost of transferring one cord of shortwood from bobtail truck to ten cord truck.
BTUNLOAD	=	Cost of unloading one cord of shortwood from three cord truck.
CAP	=	Capacity of truck in cords in TRUCKRATE procedure.
CONS	=	Cost of truck consumables per hour including gas, oil, and lubrication in TRUCKRATE procedure.
CPT	=	Cost per truck of transporting one load of wood in TRUCKRATE procedure.
DEG1	=	Formal parameter of the DISTANCE procedure denoting the compass heading from the mill to point 1.
DEG2	=	Formal parameter of the DISTANCE procedure denoting the compass heading from the mill to point 2.
DIST	=	Formal parameter of the DISTANCE procedure denoting the distance between points 1 and 2.
DISTANCE	=	Procedure to compute the distance between any two points in the area under consideration, neither of which is a landing.
DIST1	=	Formal parameter of the DISTANCE procedure denoting the distance from point 1 to the mill.
DIST2	=	Formal parameter of the DISTANCE procedure denoting the distance from point 2 to the mill.
DISTX	=	X component of TDIST.

GLOSSARY OF TERMS (continued)

DISTY	=	Y component of TDIST.
DLB	=	Computed distance from landing to between-forest dealer.
DLDIST [I,J]	=	Distance from dealer location to landing J in forest I.
DLM	=	Computed distance from landing to mill.
DLRAD [I,J]	=	Compass heading from dealer location to landing J in forest I.
DMH	=	Computed hauling cost from dealer to mill.
DSAW	=	Cost of bucking one cord of wood at the rail dealer.
FBD	=	Computed distance from forest dealer to between-forest dealer.
FBH	=	Computed cost from forest dealer to between-forest dealer.
FMDIST [I]	=	Distance from mill to dealer location within forest I.
FMRAD [I]	=	Compass heading (in degrees) from mill to dealer location within forest I.
FRPUP [M,N]	=	Forests served by between-forest rail dealer M.
FTPUP [K,L]	=	Forests served by between-forest truck dealer K.
GDEG	=	Formal parameter of the GDISTANCE procedure denoting the compass heading from the dealer location to the landing under consideration.
GDIST	=	Formal parameter of the GDISTANCE procedure denoting the distance from the landing to the dealer location within the forest.
GDISTANCE	=	Procedure to compute the distance between two points in the area under consideration, one of which is a landing.
HDIST	=	Formal parameter of the TRUCKRATE procedure denoting the distance wood is moved by a particular truck.

GLOSSARY OF TERMS (continued)

IDEG	=	Formal parameter of the GDISTANCE procedure denoting the compass heading from the mill to the dealer location within the forest containing the landing under consideration.
IDIST	=	Formal parameter of the GDISTANCE procedure denoting the distance from the mill to the dealer location within the forest containing the landing under consideration.
LBH	=	Computed cost from landing to between-forest dealer.
LDH	=	Computed hauling cost from landing to dealer.
LLOAD	=	Cost of loading one cord of longwood on ten cord truck.
LMH	=	Computed hauling cost from landing to mill.
LPH	=	Labor rate per hour in TRUCKRATE procedure.
LUNLOAD	=	Cost of unloading one cord of longwood from ten cord truck.
MAINT	=	Truck maintenance cost per day in TRUCKRATE procedure.
MINCOST [I,J]	=	Cost of minimum cost option from landing I,J.
MINCOSTS [I,J]	=	Cost of minimum shortwood option from landing I,J.
MINOPT [I,J]	=	Number of minimum cost option from landing I,J.
MINOPTS [I,J]	=	Number of minimum shortwood option from landing I,J.
MSAW	=	Cost of bucking one cord of wood at the mill.
NAREA	=	Number of forests which input wood to the mill under consideration.
NFRPUP [M]	=	Number of forests served by between-forest rail dealer M.
NFTPUP [K]	=	Number of forests served by between-forest truck dealer K.

GLOSSARY OF ITEMS (continued)

NLAND [I]	=	Number of landings within forest I.
NRPUP	=	Number of between-forest rail dealer points.
NTPUP	=	Number of between-forest truck dealer points.
OL	=	Factor for adjusting truck capacity for overload in TRUCKRATE procedure.
OPT [I,J,D]	=	Cost of shipping one cord of wood from landing J in forest I by option D.
OPTIMIZE	=	Procedure for determining the least cost option for transporting wood from landing I, J, to the mill.
OPTIMIZES	=	Procedure for determining the least cost shortwood option for transporting wood from landing I, J to the mill.
OT	=	Operating time of truck per round trip haul.
PALL	=	Cost per day of using pallets on the truck in TRUCKRATE procedure.
PBTLOAD	=	Cost of loading one cord of palletized shortwood on a three cord truck.
PBTRRTRANS	=	Cost of transferring one cord of palletized shortwood from three cord truck to rail car.
PBTTCTRANS	=	Cost of transferring one cord of palletized shortwood from three cord truck to ten cord truck.
PBTUNLOAD	=	Cost of unloading one cord of palletized shortwood from three cord truck.
PTCLOAD	=	Cost of loading one cord of palletized shortwood on ten cord truck.
PTCRRTRANS	=	Cost of transferring one cord of palletized shortwood from ten cord to rail car.
PTCUNLOAD	=	Cost of unloading one cord of palletized shortwood from a ten cord truck.
R1	=	Roundtrip distance traveled off the forest road in TRUCKRATE procedure.

GLOSSARY OF TERMS (continued)

R2	=	Roundtrip distance traveled on the forest road in TRUCKRATE procedure
R3	=	Roundtrip distance traveled out of the forest in TRUCKRATE procedure.
RAD1	=	DEG1 converted to radians.
RAD2	=	DEG2 converted to radians
RADB	=	BDEG converted to radians
RADG	=	GDEG converted to radians
RADI	=	IDEG converted to radians
RAILRATE	=	Procedure used to compute rail cost of transporting wood.
RCOST [RDIST[II]]	=	Array of applicable costs in RAILRATE procedure.
RDIST [II]	=	Array of applicable distances in RAILRATE procedure.
RMDIST [M]	=	Distance from mill to between-forest rail dealer M.
RMRAD [M]	=	Compass heading from mill to between-forest rail dealer M.
RPUP [I]	=	Array of numbers denoting the between-forest rail pickup point serving forest I. If equal to zero, no between-forest point serves the forest.
RRCOST	=	Formal parameter of RAILRATE procedure denoting the cost to ship one cord of wood a distance of RRDIST.
RRDIST	=	Formal parameter of RAILRATE procedure denoting the distance from the rail dealer to the mill.
RRUNLOAD	=	Cost of unloading one cord of shortwood at the mill from rail car.
RT	=	The number of roundtrips made by each truck per day in TRUCKRATE procedure.
T	=	Total time available per day (working hours) in TRUCKRATE procedure.

GLOSSARY OF TERMS (continued)

TCLOAD	=	Cost of loading one cord of shortwood on ten cord truck.
TCOST	=	Formal parameter of the TRUCKRATE procedure denoting the cost of transporting one cord of wood, by truck, a distance of HDIST.
TCRRTRANS	=	Cost of transferring one cord of shortwood from ten cord truck to rail car.
TCUNLOAD	=	Cost of unloading one cord of shortwood from ten cord truck.
TDIST	=	Formal parameter of the GDISTANCE procedure, denoting the distance between the two points under consideration.
TMDIST [K]	=	Distance from mill to between-forest truck dealer K.
TMRAD [K]	=	Compass heading from mill to between-forest truck dealer K.
TN	=	Time of non-work per day for the truck in TRUCK-RATE procedure.
TPUP [I]	=	Array of numbers denoting the between-forest truck pickup point serving forest I. If equal to zero, no between-forest point serves the forest.
TRUCK	=	Variable denoting the type of truck transportation used.
TRUCKRATE	=	Procedure used to compute the cost of transporting wood by truck.
TRUCKTYPE	=	Formal parameter of TRUCKRATE procedure denoting the type of truck transportation used.
TUL	=	Time to load and unload a truck in TRUCKRATE procedure.
V1	=	Speed of a truck off the forest roads in TRUCK-RATE procedure.
V2	=	Speed of a truck on the forest roads in TRUCK-RATE procedure.

GLOSSARY OF TERMS (continued)

V3	=	Speed of a truck out of the forest in TRUCKRATE procedure.
VOL	=	Volume of wood, in cords, carried by truck in TRUCKRATE procedure.
WROFF	=	Truck write-off cost per day in TRUCKRATE procedure.
WSAW	=	Cost of bucking one cord of wood at the mill.
XDIST	=	X component of DIST.
XDISTB	=	X component of BDIST.
XDIST1	=	X component of DIST1.
XDIST2	=	X component of DIST2.
XDISTG	=	X component of GDIST.
XDISTI	=	X component of IDIST.
YDIST	=	Y component of DIST
YDISTB	=	Y component of BDIST
YDIST1	=	Y component of DIST1
YDIST2	=	Y component of DIST2
YDISTG	=	Y component of GDIST
YDISTI	=	Y component of IDIST

APPENDIX B

THE PROGRAM

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    BURROUGHS B-5500 ALGOL COMPILER LEVEL   5   WEDNESDAY,   3/ 4/70, 12:43 AM.

%COMPILE BIN0042/THESIS *ALGOL           ,035800012   *0042 DIX L E                0000

%PROCESS=        00000015:IO=     00000020.                                        0000
%DATA.                                                                             0000
%DATA LEDIN.                                                                       0000
%                                                                                  0000
BEGIN                                                                              0000
                                                        START OF SEGMENT **********     2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *           0000
%                                                                                  0000
%                                                                                  0000
%                                                                                  0000
%                                                                                  0000
%     THIS PROGRAM IS DESIGNED FOR USE IN THE PULPWOOD INDUSTRY AS AN              0000
%   AID IN DETERMINING THE MOST ECONOMICAL METHOD OF TRANSPORTING                 0000
%   WOOD FROM THE FOREST LANDINGS TO THE MILL. THE INPUT DATA INCLUDES            0000
%   LOCATIONS OF FORESTS, RAIL DEALERS, AND TRUCK DEALERS IN RELATION             0000
%   TO THE MILL ; AND THE LOCATION OF THE LANDINGS WITHIN EACH FOREST             0000
%   IN RELATION TO THE DEALER WITHIN EACH FOREST. THE OUTPUT CONTAINS             0000
%   A LISTING OF THE TRANSPORTATION OPTIONS BEING CONSIDERED, A LISTING           0000
%   OF EACH FOREST LANDING WITH THE COST OF EACH OPTION (IN CENTS PER             0000
%   CORD) AND A LISTING OF EACH LANDING WITH THE LEAST COST OPTION.               0000
%                                                                                  0000
%                                                                                  0000
%                                                                                  0000
%                                                                                  0000
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *           0000
FILE IN LEDIN (2,10) ;                                                             0000
FILE OUT LEDOUT 16(2,15) ;                                                         0003
INTEGER  NAREA,NTPUP,NRPUP,                                                        0007
         TRUCK,                                                                    0007
         D,E,I,J,K,L,M,N ;                                                         0007
REAL     BTLOAD,PBTLOAD,TCLOAD,PTCLOAD,LLOAD,LUNLOAD,                              0007
         BTUNLOAD,PBTUNLOAD,TCUNLOAD,PTCUNLOAD,RRUNLOAD,                           0007
         BTTCTRANS,PBTTCTRANS,BTRRTRANS,PBTRRTRANS,TCRRTRANS,PTCRRTRANS,           0007
         DLM,LMH,LDH,DMH,DLR,LRH,BMH,FBD,FBH,                                      0007
         WSAW,DSAW,MSAW ;                                                          0007
INTEGER ARRAY MINOPT[0:4,0:6] ,                                                    0007
              MINOPTS[0:4,0:6] ,                                                   0009
              TPUP,RPUP[0:4] ;                                                     0011
REAL ARRAY  FMDIST,FMRAD,TMDIST,TMRAD,RMDIST,RMRAD[0:4] ,                          0013
            NFTPUP,NFRPUP[0:4] ,                                                   0016
            DLDIST,DLRAD,MINCOST[0:4,0:6] ,                                        0018
              MINCOSTS[0:4,0:6] ,                                                  0020
            FTPUP,FRPUP[0:4,0:4] ,                                                 0022
            NLAND[0:4] ,                                                           0025
            OPT[0:4,0:6,0:15] ;                                                    0026
LABEL    TR1,TR2,TR3 ,                                                             0028
         R1,R2 ;                                                                   0028
FORMAT                                                                             0028
         FMT01(X47,26("*")) ,                                                      0028
                                                        START OF SEGMENT **********     3
         FMT02(X47,"*",X24,"*") ,                                                  0028
         FMT03(X47,"*         PULPWOOD          *") ,                              0028
         FMT04(X47,"*      TRANSPORTATION       *") ,                              0028
         FMT05(X47,"*      COST  ANALYSIS       *") ,                              0028
         FMT06(X24,"THE FOLLOWING OPTIONS ARE CONSIDERED FOR EACH LAND"            0028
              "ING WITHIN THE FORESTS") ,                                          0028
         FMT07(X24,72("*")//////                                                   0028
              X10,"OPTION  1 - SHORTWOOD SHIPPED FROM LANDING TO MILL "            0028
```

```
      "ON BOBTAIL TRUCK."//X10,"OPTION  2 - SHORTWOOD SHIPPED "          0028
      "FROM LANDING TO MILL ON 10 CORD TRUCK."//X10,"OPTION  3 "         0028
      "- SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER ON "            0028
      "BOBTAIL TRUCK, FROM FOREST DEALER TO"/X22,"MILL ON 10 "           0028
      "CORD TRUCK."//X10,"OPTION  4 - SHORTWOOD SHIPPED FROM "           0028
      "LANDING TO FOREST DEALER ON BOBTAIL TRUCK, FROM FOREST "          0028
      "DEALER TO"/X22,"MILL ON 10 CORD TRUCK(PALLETIZED)."//X10,         0028
      "OPTION  5 - SHORTWOOD SHIPPED FROM LANDING TO FOREST "            0028
      "DEALER ON BOBTAIL TRUCK, FROM FOREST DEALER TO"/X22,              0028
      "MILL BY RAIL."//X10,"OPTION  6 - SHORTWOOD SHIPPED FROM "         0028
      "LANDING TO FOREST DEALER ON 10 CORD TRUCK, FROM FOREST "          0028
      "DEALER TO"/X22,"MILL BY RAIL."//X10,"OPTION  7 - "                0028
      "SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-FOREST DEALER "         0028
      "ON BOBTAIL TRUCK, FROM DEALER TO"/X22,"MILL BY 10 CORD "          0028
      "TRUCK."//X10,"OPTION  8 - SHORTWOOD SHIPPED FROM LANDING"         0028
      " TO BETWEEN-FOREST DEALER ON BOBTAIL TRUCK, FROM DEALER "         0028
      "TO"/X22,"MILL BY 10 CORD TRUCK(PALLETIZED)."//X10,                0028
      "OPTION  9 - SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-"           0028
      "FOREST RAIL DEALER ON BOBTAIL TRUCK, FROM RAIL"/X22,              0028
      "DEALER TO MILL BY RAIL."//X10,"OPTION 10 - SHORTWOOD "            0028
      "SHIPPED FROM LANDING TO BETWEEN-FOREST RAIL DEALER ON "           0028
      "10 CORD TRUCK, FROM RAIL"/X22,"DEALER TO MILL BY RAIL."//         0028
      X10,"OPTION 11 - SHORTWOOD SHIPPED FROM LANDING TO FOREST"         0028
      " DEALER BY BOBTAIL TRUCK, FROM FOREST DEALER TO"/X22,             0028
      "BETWEEN-AREA RAIL DEALER BY 10 CORD TRUCK, FROM RAIL "            0028
      "DEALER TO MILL BY RAIL."//X10,"OPTION 12 - SHORTWOOD "            0028
      "SHIPPED FROM LANDING TO FOREST DEALER BY BOBTAIL TRUCK, "         0028
      "FROM FOREST DEALER TO"/X22,"BETWEEN-AREA RAIL DEALER BY "         0028
      "10 CORD TRUCK, FROM RAIL DEALER TO MILL BY RAIL"                  0028
      "(PALLETIZED)."//X10,"OPTION 13 - LONGWOOD SHIPPED FROM "          0028
      "LANDING TO MILL BY 10 CORD TRUCK."//X10,"OPTION 14 - "            0028
      "LONGWOOD SHIPPED FROM LANDING TO FOREST DEALER BY 10 "            0028
      "CORD TRUCK, FROM FOREST DEALER TO"/X22,"MILL BY RAIL. "           0028
      "LONGWOOD IS CUT INTO SHORTWOOD AT RAIL DEALER."//X10,             0028
      "OPTION 15 - LONGWOOD SHIPPED FROM LANDING TO BETWEEN-"            0028
      "AREA RAIL DEALER BY 10 CORD TRUCK, FROM RAIL"/X22,                0028
      "DEALER TO MILL BY RAIL. LONGWOOD IS CUT INTO SHORTWOOD "          0028
      "AT RAIL DEALER.") ,                                               0028
                                                       3 IS  470 LONG, NEXT SEG    2
                                                     START OF SEGMENT **********   4
FMT08(X45,"FOREST, LANDING AND DEALER DATA") ,                           0028
FMT09(X45,31("*")//) ,                                                   0028
FMT10(X45,"NUMBER OF FORESTS = ",I2) ,                                   0028
FMT11(X45,"NUMBER OF BETWEEN-FOREST TRUCK DEALERS = ",I2) ,              0028
FMT12(X45,"NUMBER OF BETWEEN-FOREST RAIL DEALERS  = ",I2//) ,            0028
FMT13(X10,"FOREST AND LANDING LOCATIONS"/) ,                             0028
FMT14(X41,"COMPASS") ,                                                   0028
FMT15(X28,"DISTANCE",X5,"HEADING",X20,"DISTANCE FROM",X5,                0028
     "COMPASS HEADING") ,                                                0028
FMT16(X16,"FOREST #",X4,"FROM MILL",X4,"FROM MILL",X7,                   0028
     "LANDING #",X3,"FOREST DEALER",X5,"FROM FOREST DEALER") ,           0028
FMT17(X29,"(MILES)",X5,"(DEGREES)",X21,"(MILES)",X12,                    0028
     "(DEGREES)") ,                                                      0028
FMT18(X18,I2,X9,F6.2,X7,F6.2) ,                                          0028
FMT19(X59,I2,X11,F5.2,X14,F6.2) ,                                        0028
FMT20(X10,"BETWEEN-FOREST TRUCK DEALER LOCATIONS") ,                     0028
FMT21(X16,"TRUCK",X6,"DISTANCE",X6,"HEADING",X6,"FORESTS") ,             0028
FMT22(X16,"DEALER #    FROM MILL     FROM MILL",X4,"SERVED") ,           0028
FMT23(X28,"(MILES)",X6,"(DEGREES)"/) ,                                   0028
FMT24(X18,I2,X8,F6.2,X7,F6.2,X8,I2,I2,I2,I2) ,                           0028
FMT25(X10,"BETWEEN-FOREST RAIL DEALER LOCATIONS"/) ,                     0028
FMT26(X16,"RAIL",X7,"DISTANCE",X6,"HEADING",X6,"FORESTS") ,              0028
```

```
FMT27(X35,"COST OF OPTIONS FOR EACH LANDING (CENTS PER CORD)"      0028
     ) ,                                                           0028
FMT28(X35,49("*")//) ,                                             0028
FMT29(X10,"FOREST  LANDING",X45,"OPTION"/) ,                       0028
                                                 4 IS  261 LONG, NEXT SEG    2
                                               START OF SEGMENT **********   5
FMT30(X12,I2,X6,I2,X8,"1 =  ",F8.2,X6,"2 =  ",F8.2,X6,"3 =  ",     0028
     F8.2,X6,"4 =  ",F8.2,X6,"5 =  ",F8.2/X30,"6 =  ",F8.2,X6,     0028
     "7 =  ",F8.2,X6,"8 =  ",F8.2,X6,"9 =  ",F8.2,X5,"10 =  ",     0028
     F8.2/X29,"11 =  ",F8.2,X5,"12 =  ",F8.2,X5,"13 =  ",F8.2,     0028
     X5,"14 =  ",F8.2,X5,"15 =  ",F8.2) ,                          0028
FMT31(X35,"LEAST COST OPTION FOR EACH LANDING (CENTS PER"          0028
     " CORD)") ,                                                   0028
FMT32(X35,51("*")//) ,                                             0028
FMT33(X34,"FOREST   LANDING   LEAST COST OPTION   "                0028
     "COST OF OPTION"/) ,                                          0028
FMT34(X35,I2,X8,I2,X13,I2,X13,F8.2/) ,                             0028
FMT35(X30,"LEAST COST SHORTWOOD OPTION FOR EACH LANDING "          0028
     "(CENTS PER CORD)") ,                                         0028
FMT36(X30,61("*")//) ;                                             0028
                                                 5 IS  127 LONG, NEXT SEG    2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0028
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0028
    PROCEDURE HEADING ;                                            0028
    BEGIN                                                          0028
    INTEGER  I ;                                                   0028
                                               START OF SEGMENT **********   6
    WRITE(LEDOUT[PAGE]) ;                                          0000
    WRITE(LEDOUT[5]) ;                                             0004
    WRITE(LEDOUT,FMT01) ;                                          0008
    WRITE(LEDOUT,FMT02) ;                                          0011
    WRITE(LEDOUT,FMT03) ;                                          0014
    WRITE(LEDOUT,FMT02) ;                                          0017
    WRITE(LEDOUT,FMT04) ;                                          0020
    WRITE(LEDOUT,FMT02) ;                                          0023
    WRITE(LEDOUT,FMT05) ;                                          0026
    WRITE(LEDOUT,FMT02) ;                                          0029
    WRITE(LEDOUT,FMT01) ;                                          0032
    WRITE(LEDOUT[PAGE]) ;                                          0035
    FOR I := 1 STEP 1 UNTIL 4 DO                                   0039
    WRITE(LEDOUT) ;                                                0041
    WRITE(LEDOUT,FMT06) ;                                          0047
    WRITE(LEDOUT,FMT07) ;                                          0050
    END OF HEADING ;                                               0053
                                                 6 IS   56 LONG, NEXT SEG    2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0028
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   0028
    PROCEDURE INITIALIZE ;                                         0028
    BEGIN                                                          0028
    LABEL IN1,IN2 ;                                                0028
                                               START OF SEGMENT **********   7
    BTLOAD := 437 ;                                                0000
    PBTLOAD := 450 ;                                               0000
    TCLOAD := 437 ;                                                0001
    PTCLOAD := 450 ;                                               0002
    BTUNLOAD := 70 ;                                               0003
    PBTUNLOAD := 70 ;                                              0003
    TCUNLOAD := 70 ;                                               0004
    PTCUNLOAD := 70 ;                                              0005
    BTTCTRANS := 70 ;                                              0006
    PBTTCTRANS := 70 ;                                             0006
    BTRRTRANS := 70 ;                                              0007
```

```
          PRTRRTRANS := 70 ;                                                    0008
          TCRRTRANS := 70 ;                                                     0009
          PTCRRTRANS := 70 ;                                                    0009
          WSAW := 180 ;                                                         0010
          USAW := 90 ;                                                          0011
          NSAW := 50 ;                                                          0012
          RROULOAD := 70 ;                                                      0012
          CLOAD := 360 ;                                                        0013
          CUNLOAD := 70 ;                                                       0014
          FOR I := 1 STEP 1 UNTIL NAREA DO                                      0015
            BEGIN                                                               0016
              TPUP[I] := 0 ;                                                    0016
              RPUP[I] := 0 ;                                                    0017
            END ;                                                               0018
          IF NTPUP EQL 0 THEN GO TO IN1 ;                                       0020
          FOR K := 1 STEP 1 UNTIL NTPUP DO                                      0022
          FOR L := 1 STEP 1 UNTIL NFTPUP[K] DO                                  0023
            BEGIN                                                               0027
              I := FTPUP[K,L] ;                                                 0027
              TPUP[I] := K ;                                                    0028
            END ;                                                               0030
IN1:      IF NRPUP EQL 0 THEN GO TO IN2 ;                                       0032
          FOR M := 1 STEP 1 UNTIL NRPUP DO                                      0034
          FOR N := 1 STEP 1 UNTIL NFRPUP[M] DO                                  0035
            BEGIN                                                               0039
              I := FRPUP[M,N] ;                                                 0039
              RPUP[I] := M ;                                                    0040
            END ;                                                               0042
IN2:      FOR I := 1 STEP 1 UNTIL NAREA DO                                      0044
          FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                   0046
          FOR D := 1 STEP 1 UNTIL 15 DO                                         0050
          UPT[I,J,D] := 99999.99 ;                                              0051
          END OF INITIALIZE ;                                                   0060
                                                    7 IS   61 LONG, NEXT SEG     2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     0028
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     0028
          PROCEDURE DISTANCE(DIST1,DEG1,DIST2,DEG2,DIST) ;                      0028
          REAL  DIST1,DEG1,DIST2,DEG2,DIST ;                                    0028
          BEGIN                                                                 0028
          REAL  RAD1,RAD2,XDIST1,XDIST2,YDIST1,YDIST2,XDIST,YDIST ;             0028
                                                START OF SEGMENT **********     8
          RAD1 := 0.01745329×DEG1 ;                                             0000
          RAD2 := 0.01745329×DEG2 ;                                             0001
          XDIST1 := DIST1×SIN(RAD1) ;                                           0002
          YDIST1 := DIST1×COS(RAD1) ;                                           0004
          XDIST2 := DIST2×SIN(RAD2) ;                                           0006
          YDIST2 := DIST2×COS(RAD2) ;                                           0007
          XDIST := ABS(XDIST1-XDIST2) ;                                         0009
          YDIST := ABS(YDIST1-YDIST2) ;                                         0011
          DIST := SQRT(XDIST*2+YDIST*2) ;                                       0012
          END OF DISTANCE ;                                                     0013
                                                    8 IS   20 LONG, NEXT SEG     2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     0028
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *     0028
          PROCEDURE GDISTANCE(BDIST,BDEG,IDIST,IDEG,GDIST,GDEG,TDIST) ;          0028
          REAL   BDIST,BDEG,IDIST,IDEG,GDIST,GDEG,TDIST ;                       0028
          BEGIN                                                                 0028
          REAL   XDISTB,YDISTB,XDISTI,YDISTI,XDISTG,YDISTG,                     0028
                                                START OF SEGMENT **********     9
                 RADB,RADI,RADG,DISTX,DISTY ;                                   0000
          LABEL  GL1,GL2 ;                                                      0000
          IF BDIST NEQ 0 THEN GO TO GL1 ;                                       0000
```

73

```
         XDISTB := 0 ;                                                          0001
         YDISTB := 0 ;                                                          0002
         GO TO GL2 ;                                                            0002
GL1:     RADB := 0.01745329×BDEG ;                                              0003
         XDISTB := BDIST×SIN(RADB) ;                                            0005
         YDISTB := BDIST×COS(RADB) ;                                            0007
GL2:     RADI := 0.01745329×IDEG ;                                              0008
         RADG := 0.01745329×GDEG ;                                              0010
         XDISTI := IDIST×SIN(RADI) ;                                            0011
         YDISTI := IDIST×COS(RADI) ;                                            0013
         XDISTG := GDIST×SIN(RADG) ;                                            0015
         YDISTG := GDIST×COS(RADG) ;                                            0016
         DISTX := ABS(XDISTI+XDISTG-XDISTB) ;                                   0018
         DISTY := ABS(YDISTI+YDISTG-YDISTB) ;                                   0020
         TDIST := SQRT(DISTX*2+DISTY*2) ;                                       0022
         END OF GDISTANCE ;                                                     0025
                                                          V IS    31 LONG, NEXT SEG     2
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *        0028
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *        0028
         PROCEDURE TRUCKRATE(TRUCKTYPE,HDIST,TCOST) ;                            0028
         INTEGER TRUCKTYPE ;                                                    0028
         REAL HDIST,TCOST ;                                                     0028
         BEGIN                                                                  0028
         INTEGER V1,V2,V3 ;                                                     0028
                                                     START OF SEGMENT **********    10
         REAL CAP,I,IN,LPH,                                                     0000
              TUL,WRUFF,MAINT,CONS,PALL,                                        0000
              R1,R2,R3,OL,VOL,                                                  0000
              RI,RIE,RT1,RT2,RT3,OT,CPT ;                                       0000
         V1 := 5 ;                                                              0000
         V2 := 15 ;                                                             0000
         V3 := 45 ;                                                             0001
         I := 8 ;                                                               0002
         IN := 1 ;                                                              0003
         LPH := 200 ;                                                           0003
         IF TRUCKTYPE EQL 1 THEN                                                0004
           BEGIN                                                                0005
             CAP := 3 ;                                                         0005
             TUL := 1.5 ;                                                       0006
             WRUFF := 425 ;                                                     0007
             MAINT := 425 ;                                                     0008
             CONS := 166.7 ;                                                    0008
             PALL := 0 ;                                                        0009
             R1 := 4 ;                                                          0010
             R2 := 40 ;                                                         0011
             R3 := 2×HDIST-44 ;                                                 0011
           END ELSE                                                             0013
         IF TRUCKTYPE EQL 2 THEN                                                0013
           BEGIN                                                                0016
             CAP := 9.8 ;                                                       0017
             TUL := 5.0 ;                                                       0018
             WRUFF := 1675 ;                                                    0018
             MAINT := 838 ;                                                     0019
             CONS := 77 ;                                                       0020
             PALL := 0 ;                                                        0021
             R1 := 4 ;                                                          0021
             R2 := 40 ;                                                         0022
             R3 := 2×HDIST-44 ;                                                 0023
           END ELSE                                                             0025
         IF TRUCKTYPE EQL 3 THEN                                                0025
           BEGIN                                                                0029
             CAP := 3 ;                                                         0030
```

```
    TUL := 1.5 ;                                    0031
    WRUFF := 425 ;                                  0031
    MAINT := 425 ;                                  0032
    CONS := 166.7 ;                                 0033
    PALL := 0 ;                                     0034
    R1 := 4 ;                                       0034
    R2 := 2×HDIST-4 ;                               0035
    R3 := 0 ;                                       0037
  END ELSE                                          0038
IF TRUCKTYPE EQL 4 THEN                             0038
  BEGIN                                             0041
    CAP := 9.8 ;                                    0042
    TUL := 1.57 ;                                   0043
    WRUFF := 1675 ;                                 0043
    MAINT := 838 ;                                  0044
    CONS := 77 ;                                    0045
    PALL := 0 ;                                     0046
    R1 := 0 ;                                       0046
    R2 := 40 ;                                      0047
    R3 := 2×HDIST-40 ;                              0048
  END ELSE                                          0050
IF TRUCKTYPE EQL 5 THEN                             0050
  BEGIN                                             0054
    CAP := 2.75 ;                                   0055
    TUL := 0.5 ;                                    0056
    WRUFF := 425 ;                                  0056
    MAINT := 425 ;                                  0057
    CONS := 166.7 ;                                 0058
    PALL := 134.5 ;                                 0059
    R1 := 4 ;                                       0059
    R2 := 2×HDIST-4 ;                               0060
    R3 := 0 ;                                       0062
  END ELSE                                          0063
IF TRUCKTYPE EQL 6 THEN                             0063
  BEGIN                                             0068
    CAP := 9.05 ;                                   0069
    TUL := 1.67 ;                                   0070
    WRUFF := 1675 ;                                 0070
    MAINT := 838 ;                                  0071
    CONS := 77 ;                                    0072
    PALL := 358 ;                                   0073
    R1 := 0 ;                                       0073
    R2 := 40 ;                                      0074
    R3 := 2×HDIST-40 ;                              0075
  END ELSE                                          0077
IF TRUCKTYPE EQL 7 THEN                             0077
  BEGIN                                             0081
    CAP := 9.9 ;                                    0082
    TUL := 5.0 ;                                    0083
    WRUFF := 1675 ;                                 0083
    MAINT := 838 ;                                  0084
    CONS := 77 ;                                    0085
    PALL := 0 ;                                     0086
    R1 := 4 ;                                       0086
    R2 := 2×HDIST-4 ;                               0087
    R3 := 0 ;                                       0089
  END ELSE                                          0090
IF TRUCKTYPE EQL 8 THEN                             0090
  BEGIN                                             0094
    CAP := 9.8 ;                                    0095
    TUL := 1.67 ;                                   0096
    WRUFF := 1675 ;                                 0096
```

```
      MAINT := 838 ;                                   0097
      CONS := 77 ;                                     0098
      PALL := 0 ;                                      0099
      R1 := 0 ;                                        0099
      R2 := 0 ;                                        0100
      R3 := 2×HDIST ;                                  0101
    END ELSE                                           0102
  IF TRUCKTYPE EQL 9 THEN                              0102
    BEGIN                                              0106
      CAP := 2.75 ;                                    0107
      TUL := 0.5 ;                                     0108
      WRUFF := 425 ;                                   0108
      MAINT := 425 ;                                   0109
      CONS := 166.7 ;                                  0110
      PALL := 134.5 ;                                  0111
      R1 := 4 ;                                        0111
      R2 := 40 ;                                       0112
      R3 := 2×HDIST-44 ;                               0113
    END ELSE                                           0115
  IF TRUCKTYPE EQL 10 THEN                             0115
    BEGIN                                              0120
      CAP := 9.05 ;                                    0121
      TUL := 1.67 ;                                    0122
      WRUFF := 1675 ;                                  0122
      MAINT := 838 ;                                   0123
      CONS := 77 ;                                     0124
      PALL := 358 ;                                    0125
      R1 := 0 ;                                        0125
      R2 := 0 ;                                        0126
      R3 := 2×HDIST ;                                  0127
    END ELSE                                           0128
  IF TRUCKTYPE EQL 11 THEN                             0128
    BEGIN                                              0132
      CAP := 9.8 ;                                     0133
      TUL := 3.33 ;                                    0134
      WRUFF := 1675 ;                                  0134
      MAINT := 338 ;                                   0135
      CONS := 77 ;                                     0136
      PALL := 0 ;                                      0137
      R1 := 4 ;                                        0137
      R2 := 40 ;                                       0138
      R3 := 2×HDIST-44 ;                               0139
    END ELSE                                           0141
  IF TRUCKTYPE EQL 12 THEN                             0141
    BEGIN                                              0145
      CAP := 9.8 ;                                     0146
      TUL := 3.33 ;                                    0147
      WRUFF := 1675 ;                                  0147
      MAINT := 838 ;                                   0148
      CONS := 77 ;                                     0149
      PALL := 0 ;                                      0150
      R1 := 4 ;                                        0150
      R2 := 2×HDIST-4 ;                                0151
      R3 := 0 ;                                        0153
    END ;                                              0154
  IF HDIST LEQ 20 THEN                                 0154
  DL := 1.2 ELSE DL := 1.0 ;                           0154
  VOL := CAP×DL ;                                      0161
  RT := (T-TN)/(TUL+R1/V1+R2/V2+R3/V3) ;               0163
  IF RT LEQ 0.5 THEN RT := 0.5 ELSE                    0167
    BEGIN                                              0169
      RTE := ENTIER(RT) ;                              0173
```

```
        RT1 := RTE+0.25 ;                                                              0174
        RT2 := RTE+0.50 ;                                                              0176
        RT3 := RTE+0.75 ;                                                              0177
        IF RTE LEQ RT LSS RT1 THEN RT := RTE ;                                         0178
        IF RT1 LEQ RT LSS RT3 THEN RT := RT2 ;                                         0182
        IF RT3 LEQ RT THEN RT := RTE+1 ;                                               0185
      END ;                                                                            0188
    UT := (R1/V1+R2/V2+R3/V3) ;                                                        0188
    CPT := LPH×(UT+TUL+TN/RT)+(WROFF+MAINT+PALL)/RT+CONS×UT ;                          0191
    TCOST := CPT/VOL ;                                                                 0197
    END OF TRUCKRATE ;                                                                 0198
                                                              10 IS  209 LONG, NEXT SEG     2
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                  0028
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                  0028
    PROCEDURE RAILRATE(RRDIST,RRCOST) ;                                                0028
    REAL RRDIST,RRCOST ;                                                               0028
    BEGIN                                                                              0028
    INTEGER II ;                                                                       0028
                                                              START OF SEGMENT **********   11
    LABEL RL1 ;                                                                        0000
    REAL ARRAY RDIST[0:35],RCOST[0:600] ;                                              0000
    RDIST[1] := 10 ;     RCOST[10] := 178.45 ;                                         0003
    RDIST[2] := 15 ;     RCOST[15] := 196.83 ;                                         0006
    RDIST[3] := 30 ;     RCOST[30] := 209.81 ;                                         0008
    RDIST[4] := 40 ;     RCOST[40] := 240.09 ;                                         0011
    RDIST[5] := 50 ;     RCOST[50] := 270.38 ;                                         0013
    RDIST[6] := 70 ;     RCOST[70] := 301.74 ;                                         0016
    RDIST[7] := 90 ;     RCOST[90] := 332.02 ;                                         0018
    RDIST[8] := 110 ;    RCOST[110] := 362.30 ;                                        0021
    RDIST[9] := 130 ;    RCOST[130] := 392.58 ;                                        0023
    RDIST[10] := 150 ;   RCOST[150] := 420.70 ;                                        0026
    RDIST[11] := 170 ;   RCOST[170] := 450.99 ;                                        0028
    RDIST[12] := 190 ;   RCOST[190] := 483.43 ;                                        0031
    RDIST[13] := 210 ;   RCOST[210] := 512.63 ;                                        0033
    RDIST[14] := 230 ;   RCOST[230] := 542.91 ;                                        0036
    RDIST[15] := 250 ;   RCOST[250] := 574.28 ;                                        0038
    RDIST[16] := 270 ;   RCOST[270] := 605.64 ;                                        0041
    RDIST[17] := 290 ;   RCOST[290] := 638.09 ;                                        0043
    RDIST[18] := 310 ;   RCOST[310] := 668.37 ;                                        0046
    RDIST[19] := 330 ;   RCOST[330] := 698.65 ;                                        0048
    RDIST[20] := 350 ;   RCOST[350] := 732.18 ;                                        0051
    RDIST[21] := 370 ;   RCOST[370] := 762.46 ;                                        0053
    RDIST[22] := 390 ;   RCOST[390] := 793.82 ;                                        0056
    RDIST[23] := 400 ;   RCOST[400] := 824.10 ;                                        0058
    RDIST[24] := 410 ;   RCOST[410] := 824.10 ;                                        0061
    RDIST[25] := 430 ;   RCOST[430] := 856.55 ;                                        0063
    RDIST[26] := 450 ;   RCOST[450] := 887.91 ;                                        0066
    RDIST[27] := 470 ;   RCOST[470] := 918.19 ;                                        0068
    RDIST[28] := 490 ;   RCOST[490] := 948.48 ;                                        0071
    RDIST[29] := 510 ;   RCOST[510] := 982.00 ;                                        0073
    RDIST[30] := 530 ;   RCOST[530] := 1012.28 ;                                       0076
    RDIST[31] := 550 ;   RCOST[550] := 1043.65 ;                                       0078
    RDIST[32] := 570 ;   RCOST[570] := 1073.93 ;                                       0081
    RDIST[33] := 590 ;   RCOST[590] := 1106.37 ;                                       0083
    RDIST[34] := 600 ;   RCOST[600] := 1137.74 ;                                       0086
    FOR II := 1 STEP 1 UNTIL 35 DO                                                     0088
    IF RDIST[II] ≥ RRDIST THEN GO TO RL1 ;                                             0123
RL1:    RRCOST := RCOST[RDIST[II]] ;                                                   0126
    END OF RAILRATE ;                                                                  0128
                                                              11 IS  133 LONG, NEXT SEG     2
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                  0028
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                  0028
```

```
        PROCEDURE OPTIMIZE ;                                                     0028
        BEGIN                                                                    0028
        MINOPT[I,J] := 0 ;                                                       0028
        MINCOST[I,J] := 99999.99 ;                                               0032
        FOR D := 1 STEP 1 UNTIL 15 DO                                            0034
        IF OPT[I,J,D] LSS MINCOST[I,J] THEN                                      0036
          BEGIN                                                                  0039
            MINCOST[I,J] := OPT[I,J,D] ;                                         0040
            MINOPT[I,J] := D ;                                                   0043
          END ;                                                                  0045
        END OF OPTIMIZE ;                                                        0048
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *      0048
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *      0048
        PROCEDURE OPTIMIZES ;                                                    0048
        BEGIN                                                                    0048
        MINOPTS[I,J] := 0 ;                                                      0048
        MINCOSTS[I,J] := 99999.99 ;                                              0051
        FOR E := 1 STEP 1 UNTIL 12 DO                                            0053
        IF OPT[I,J,E] LSS MINCOSTS[I,J] THEN                                     0055
          BEGIN                                                                  0058
            MINCOSTS[I,J] := OPT[I,J,E] ;                                        0059
            MINOPTS[I,J] := E ;                                                  0062
          END ;                                                                  0064
        END OF OPTIMIZES ;                                                       0067
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *      0067
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *      0067
        PROCEDURE OUTPUT ;                                                       0067
        BEGIN                                                                    0067
        WRITE(LEDOUT[PAGE]) ;                                                    0067
        WRITE(LEDOUT,FMT08) ;                                                    0072
        WRITE(LEDOUT,FMT09) ;                                                    0075
        WRITE(LEDOUT,FMT10,NAREA) ;                                              0078
        WRITE(LEDOUT,FMT11,NTPUP) ;                                              0085
        WRITE(LEDOUT,FMT12,NRPUP) ;                                              0093
        WRITE(LEDOUT,FMT13) ;                                                    0101
        WRITE(LEDOUT,FMT14) ;                                                    0104
        WRITE(LEDOUT,FMT15) ;                                                    0107
        WRITE(LEDOUT,FMT16) ;                                                    0110
        WRITE(LEDOUT,FMT17) ;                                                    0113
        FOR I := 1 STEP 1 UNTIL NAREA DO                                         0116
          BEGIN                                                                  0117
            WRITE(LEDOUT) ;                                                      0117
            WRITE(LEDOUT,FMT18,I,FMDIST[I],FMRAD[I]) ;                           0121
            FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                  0133
            WRITE(LEDOUT,FMT19,J,DLDIST[I,J],DLRAD[I,J]) ;                       0137
          END ;                                                                  0152
        WRITE(LEDOUT) ;                                                          0155
        WRITE(LEDOUT) ;                                                          0159
        WRITE(LEDOUT,FMT20) ;                                                    0163
        WRITE(LEDOUT,FMT14) ;                                                    0166
        WRITE(LEDOUT,FMT21) ;                                                    0169
        WRITE(LEDOUT,FMT22) ;                                                    0172
        WRITE(LEDOUT,FMT23) ;                                                    0175
        FOR K := 1 STEP 1 UNTIL NTPUP DO                                         0178
        WRITE(LEDOUT,FMT24,K,TMDIST[K],TMRAD[K],FOR L := 1 STEP 1                0179
             UNTIL NFTPUP[K] DO FTPUP[K,L]) ;                                    0188
        WRITE(LEDOUT) ;                                                          0200
        WRITE(LEDOUT) ;                                                          0204
        WRITE(LEDOUT,FMT25) ;                                                    0208
        WRITE(LEDOUT,FMT14) ;                                                    0211
        WRITE(LEDOUT,FMT26) ;                                                    0214
        WRITE(LEDOUT,FMT22) ;                                                    0217
```

```
        WRITE(LEDOUT,FMT23) ;                                                        0220
        FOR M := 1 STEP 1 UNTIL NRPUP DO                                             0223
        WRITE(LEDOUT,FMT24,M,RMDIST[M],RMRAD[M], FOR N := 1 STEP 1                   0225
             UNTIL NFRPUP[M] DO FRPUP[M,N]) ;                                        0234
        WRITE(LEDOUT[PAGE]) ;                                                        0246
        WRITE(LEDOUT,FMT27) ;                                                        0250
        WRITE(LEDOUT,FMT28) ;                                                        0253
        WRITE(LEDOUT,FMT29) ;                                                        0256
        FOR I := 1 STEP 1 UNTIL NAREA DO                                             0259
        FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                          0261
          BEGIN                                                                      0265
            WRITE(LEDOUT) ;                                                          0265
            WRITE(LEDOUT,FMT30,I,J, FOR D := 1 STEP 1 UNTIL 15 DO                    0269
                 OPT[I,J,D]) ;                                                       0278
          END ;                                                                      0286
        WRITE(LEDOUT[PAGE]) ;                                                        0289
        WRITE(LEDOUT,FMT31) ;                                                        0293
        WRITE(LEDOUT,FMT32) ;                                                        0296
        WRITE(LEDOUT,FMT33) ;                                                        0299
        FOR I := 1 STEP 1 UNTIL NAREA DO                                             0302
        FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                          0303
        WRITE(LEDOUT,FMT34,I,J,MINOPT[I,J],MINCOST[I,J]) ;                           0307
        WRITE(LEDOUT[PAGE]) ;                                                        0325
        WRITE(LEDOUT,FMT35) ;                                                        0329
        WRITE(LEDOUT,FMT36) ;                                                        0332
        WRITE(LEDOUT,FMT33) ;                                                        0335
        FOR I := 1 STEP 1 UNTIL NAREA DO                                             0338
        FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                          0339
        WRITE(LEDOUT,FMT34,I,J,MINOPTS[I,J],MINCOSTS[I,J]) ;                         0343
        END OF OUTPUT ;                                                              0361
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                      0368
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                      0368
% * * * * *                         PROGRAM                  * * * * *              0368
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                      0368
% * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *                      0368
        WRITE(LEDOUT[NO]) ;                                                          0368
        READ(LEDIN,/,NAREA) ;                                                        0372
        FOR I := 1 STEP 1 UNTIL NAREA DO                                             0379
        READ(LEDIN,/,FMDIST[I],FMRAD[I],NLAND[I],FOR J := 1 STEP 1                   0381
            UNTIL NLAND[I] DO [DLDIST[I,J],DLRAD[I,J]]) ;                            0390
        READ(LEDIN,/,NTPUP) ;                                                        0406
        IF NTPUP EQL 0 THEN GO TO R1 ;                                               0413
        FOR K := 1 STEP 1 UNTIL NTPUP DO                                             0415
        READ(LEDIN,/,TMDIST[K],TMRAD[K],NFTPUP[K],FOR L := 1 STEP 1                  0416
            UNTIL NFTPUP[K] DO FTPUP[K,L]) ;                                         0425
R1:     READ(LEDIN,/,NRPUP) ;                                                        0438
        IF NRPUP EQL 0 THEN GO TO R2 ;                                               0445
        FOR M := 1 STEP 1 UNTIL NRPUP DO                                             0447
        READ(LEDIN,/,RMDIST[M],RMRAD[M],NFRPUP[M],FOR N := 1 STEP 1                  0448
            UNTIL NFRPUP[M] DO FRPUP[M,N]) ;                                         0457
R2:     INITIALIZE ;                                                                 0470
        FOR I := 1 STEP 1 UNTIL NAREA DO                                             0470
        FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                          0472
        BEGIN                                                                        0476
% * * * * * * * * * *          COMPUTE OPT[I,J,1]          * * * * * * * * * *       0476
        GDISTANCE(0,0,FMDIST[I],FMRAD[I],DLDIST[I,J],DLRAD[I,J],DLM) ;               0476
        TRUCK := 1 ;                                                                 0490
        TRUCKRATE(TRUCK,DLM,LMH) ;                                                   0490
        OPT[I,J,1] := WSAW + HTLOAD + LMH + BTUNLOAD ;                               0492
% * * * * * * * * * *          COMPUTE OPT[I,J,2]          * * * * * * * * * *       0496
        TRUCK := 2 ;                                                                 0496
        TRUCKRATE(TRUCK,DLM,LMH) ;                                                   0497
```

```
         OPT[I,J,2] := WSAW + TCLOAD + LMH + TCUNLOAD ;                              0498
% * * * * * * * * * *          COMPUTE OPT[I,J,3]          * * * * * * * * * *      0502
         TRUCK := 3 ;                                                                 0502
         TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                           0503
         TRUCK := 4 ;                                                                 0506
         TRUCKRATE(TRUCK,FMDIST[I],DMH) ;                                             0508
         OPT[I,J,3] := WSAW + BTLOAD + LDH + BTTCTRANS + DMH + TCUNLOAD;             0512
% * * * * * * * * * *          COMPUTE OPT[I,J,4]          * * * * * * * * * *      0516
         TRUCK := 5 ;                                                                 0517
         TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                           0518
         TRUCK := 6 ;                                                                 0523
         TRUCKRATE(TRUCK,FMDIST[I],DMH) ;                                             0523
         OPT[I,J,4] := WSAW + PBTLOAD + LDH + PBTTCTRANS + DMH                       0527
                     + PTCUNLOAD ;                                                    0531
% * * * * * * * * * *          COMPUTE OPT[I,J,5]          * * * * * * * * * *      0532
         TRUCK := 3 ;                                                                 0532
         TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                           0533
         RAILRATE(FMDIST[I],DMH) ;                                                    0536
         OPT[I,J,5] := WSAW + BTLOAD + LDH + BTRRTRANS + DMH + RRUNLOAD;             0541
% * * * * * * * * * *          COMPUTE OPT[I,J,6]          * * * * * * * * * *      0545
         TRUCK := 7 ;                                                                 0546
         TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                           0547
         OPT[I,J,6] := WSAW + TCLOAD + LDH + TCRRTRANS + DMH + RRUNLOAD;             0552
% * * * * * * * * * *          COMPUTE OPT[I,J,7]          * * * * * * * * * *      0556
         IF TPUP[I] = 0 THEN GO TO TR1 ;                                              0557
         GDISTANCE(TMDIST[TPUP[I]],TMRAD[TPUP[I]],FMDIST[I],FMRAD[I],                0558
                   DLDIST[I,J],DLRAD[I,J],DLB) ;                                      0570
         TRUCK := 1 ;                                                                 0578
         TRUCKRATE(TRUCK,DLB,LBH) ;                                                   0578
         TRUCK := 8 ;                                                                 0580
         TRUCKRATE(TRUCK,TMDIST[TPUP[I]],BMH) ;                                       0580
         OPT[I,J,7] := WSAW + BTLOAD + LBH + BTTCTRANS + BMH + TCUNLOAD;             0584
% * * * * * * * * * *          COMPUTE OPT[I,J,8]          * * * * * * * * * *      0588
         TRUCK := 9 ;                                                                 0589
         TRUCKRATE(TRUCK,DLB,LBH) ;                                                   0590
         TRUCK := 10 ;                                                                0591
         TRUCKRATE(TRUCK,TMDIST[TPUP[I]],BMH) ;                                       0592
         OPT[I,J,8] := WSAW + PBTLOAD + LBH + PBTTCTRANS + BMH                       0596
                     + PTCUNLOAD ;                                                    0600
% * * * * * * * * * *          COMPUTE OPT[I,J,9]          * * * * * * * * * *      0601
TR1:     IF RPUP[I] = 0 THEN GO TO TR2 ;                                              0601
         GDISTANCE(RMDIST[RPUP[I]],RMRAD[RPUP[I]],FMDIST[I],FMRAD[I],                0603
                   DLDIST[I,J],DLRAD[I,J],DLB) ;                                      0615
         TRUCK := 1 ;                                                                 0623
         TRUCKRATE(TRUCK,DLB,LBH) ;                                                   0623
         RAILRATE(RMDIST[RPUP[I]],BMH) ;                                              0625
         OPT[I,J,9] := WSAW + BTLOAD + LBH + BTRRTRANS + BMH + RRUNLOAD;             0628
% * * * * * * * * * *          COMPUTE OPT[I,J,10]         * * * * * * * * * *      0632
         TRUCK := 2 ;                                                                 0633
         TRUCKRATE(TRUCK,DLB,LBH) ;                                                   0634
         OPT[I,J,10] := WSAW + TCLOAD + LBH + TCRRTRANS + BMH                        0635
                     + RRUNLOAD ;                                                     0639
% * * * * * * * * * *          COMPUTE OPT[I,J,11]         * * * * * * * * * *      0641
         DISTANCE(RMDIST[RPUP[I]],RMRAD[RPUP[I]],FMDIST[I],FMRAD[I],                 0641
                  FBD) ;                                                              0652
         TRUCK := 3 ;                                                                 0653
         TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                           0654
         TRUCK := 4 ;                                                                 0656
         TRUCKRATE(TRUCK,FBD,FBH) ;                                                   0656
         OPT[I,J,11] := WSAW + BTLOAD + LDH + BTTCTRANS + FBH                        0660
                     + TCRRTRANS + BMH + RRUNLOAD ;                                   0663
% * * * * * * * * * *          COMPUTE OPT[I,J,12]         * * * * * * * * * *      0666
```

```
                TRUCK := 5 ;                                                                        0666
                TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                                  0667
                TRUCK := 6 ;                                                                        0671
                TRUCKRATE(TRUCK,FBD,FBH) ;                                                          0671
                OPT[I,J,12] := WSAW + PBTLOAD + LDH + PBTTCTRANS + FBH                              0673
                               + PTCRRTRANS + BMH + RRUNLOAD ;                                      0676
        % * * * * * * * * * *        COMPUTE OPT[I,J,13]        * * * * * * * * * *                 0679
        TR2:    GDISTANCE(0,0,FMDIST[I],FMRAD[I],DLDIST[I,J],DLRAD[I,J],DLM) ;                      0679
                TRUCK := 11 ;                                                                       0694
                TRUCKRATE(TRUCK,DLM,LMH) ;                                                          0694
                OPT[I,J,13] := LLOAD + LMH + WSAW + LUNLOAD ;                                       0696
        % * * * * * * * * * *        COMPUTE OPT[I,J,14]        * * * * * * * * * *                 0700
                  TRUCK := 12 ;                                                                     0700
                TRUCKRATE(TRUCK,DLDIST[I,J],LDH) ;                                                  0701
                RAILRATE(FMDIST[I],DMH) ;                                                           0705
                OPT[I,J,14] := LLOAD + LDH + DSAW + TCRRTRANS + DMH + RRUNLOAD;                     0708
        % * * * * * * * * * *        COMPUTE OPT[I,J,15]        * * * * * * * * *                   0712
                IF TPUP[I] = 0 THEN GO TO TR3 ;                                                     0713
                GDISTANCE(RMDIST[RPUP[I]],RMRAD[RPUP[I]],FMDIST[I],FMRAD[I],                        0715
                          DLDIST[I,J],DLRAD[I,J],DLB) ;                                             0726
                TRUCK := 11 ;                                                                       0734
                TRUCKRATE(TRUCK,DLB,LBH) ;                                                          0734
                RAILRATE(RMDIST[RPUP[I]],BMH) ;                                                     0736
                OPT[I,J,15] := LLOAD + LBH + DSAW + TCRRTRANS + BMH + RRUNLOAD;                     0739
        TR3:    END ;                                                                               0743
                FOR I := 1 STEP 1 UNTIL NAREA DO                                                    0749
                FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                                 0751
                OPTIMIZE ;                                                                          0755
                FOR I := 1 STEP 1 UNTIL NAREA DO                                                    0758
                FOR J := 1 STEP 1 UNTIL NLAND[I] DO                                                 0760
                OPTIMIZES ;                                                                         0764
                HEADING ;                                                                           0767
                OUTPUT ;                                                                            0768
        END.                                                                                        0768
                                                                               2 IS   774 LONG, NEXT SEG     1
                                                                               1 IS     2 LONG, NEXT SEG     0
                                                                              21 IS    69 LONG, NEXT SEG     0
NUMBER OF SYNTAX ERRORS DETECTED =    0
NUMBER OF SEQUENCE ERRORS DETECTED =    0
COMPILER TIMES: PROCESSOR =    32 SECONDS; IO =    18 SECONDS; ELAPSED =    38 SECONDS
PRT SIZE =  175
TOTAL SEGMENT SIZE =  2213 WORDS
DISK SIZE =   89 SEGMENTS
NUMBER OF PROGRAM SEGMENTS =   21
ESTIMATED CORE STORAGE REQUIREMENT =  6935 WORDS
```

APPENDIX C

SAMPLE PROGRAM OUTPUT

PULPWOOD

TRANSPORTATION

COST ANALYSIS

THE FOLLOWING OPTIONS ARE CONSIDERED FOR EACH LANDING WITHIN THE FORESTS

OPTION 1 - SHORTWOOD SHIPPED FROM LANDING TO MILL ON BOBTAIL TRUCK.

OPTION 2 - SHORTWOOD SHIPPED FROM LANDING TO MILL ON 10 CORD TRUCK.

OPTION 3 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER ON BOBTAIL TRUCK, FROM FOREST DEALER TO MILL ON 10 CORD TRUCK.

OPTION 4 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER ON BOBTAIL TRUCK, FROM FOREST DEALER TO MILL ON 10 CORD TRUCK(PALLETIZED).

OPTION 5 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER ON BOBTAIL TRUCK, FROM FOREST DEALER TO MILL BY RAIL.

OPTION 6 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER ON 10 CORD TRUCK, FROM FOREST DEALER TO MILL BY RAIL.

OPTION 7 - SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-FOREST DEALER ON BOBTAIL TRUCK, FROM DEALER TO MILL BY 10 CORD TRUCK.

OPTION 8 - SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-FOREST DEALER ON BOBTAIL TRUCK, FROM DEALER TO MILL BY 10 CORD TRUCK(PALLETIZED).

OPTION 9 - SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-FOREST RAIL DEALER ON BOBTAIL TRUCK, FROM RAIL DEALER TO MILL BY RAIL.

OPTION 10 - SHORTWOOD SHIPPED FROM LANDING TO BETWEEN-FOREST RAIL DEALER ON 10 CORD TRUCK, FROM RAIL DEALER TO MILL BY RAIL.

OPTION 11 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER BY BOBTAIL TRUCK, FROM FOREST DEALER TO BETWEEN-AREA RAIL DEALER BY 10 CORD TRUCK, FROM RAIL DEALER TO MILL BY RAIL.

OPTION 12 - SHORTWOOD SHIPPED FROM LANDING TO FOREST DEALER BY BOBTAIL TRUCK, FROM FOREST DEALER TO BETWEEN-AREA RAIL DEALER BY 10 CORD TRUCK, FROM RAIL DEALER TO MILL BY RAIL(PALLETIZED).

OPTION 13 - LONGWOOD SHIPPED FROM LANDING TO MILL BY 10 CORD TRUCK.

OPTION 14 - LONGWOOD SHIPPED FROM LANDING TO FOREST DEALER BY 10 CORD TRUCK, FROM FOREST DEALER TO MILL BY RAIL. LONGWOOD IS CUT INTO SHORTWOOD AT RAIL DEALER.

OPTION 15 - LONGWOOD SHIPPED FROM LANDING TO BETWEEN-AREA RAIL DEALER BY 10 CORD TRUCK, FROM RAIL DEALER TO MILL BY RAIL. LONGWOOD IS CUT INTO SHORTWOOD AT RAIL DEALER.

FOREST, LANDING AND DEALER DATA
****

NUMBER OF FORESTS = 4
NUMBER OF BETWEEN-FOREST TRUCK DEALERS = 2
NUMBER OF BETWEEN-FOREST RAIL DEALERS = 2

FOREST AND LANDING LOCATIONS

FOREST #	DISTANCE FROM MILL (MILES)	COMPASS HEADING FROM MILL (DEGREES)	LANDING #	DISTANCE FROM FOREST DEALER (MILES)	COMPASS HEADING FROM FOREST DEALER (DEGREES)
1	235.00	10.00			
			1	20.00	0.00
			2	15.00	45.00
			3	5.00	270.00
			4	10.00	315.00
2	225.00	174.50			
			1	5.00	90.00
			2	10.00	135.00
			3	15.00	154.00
			4	20.00	196.00
3	210.00	184.00			
			1	5.00	135.00
			2	20.00	180.00
			3	15.00	225.00
			4	10.00	270.00
4	241.00	354.00			
			1	15.00	0.00
			2	20.00	47.00
			3	5.00	270.00
			4	10.00	315.00

BETWEEN-FOREST TRUCK DEALER LOCATIONS

TRUCK DEALER #	DISTANCE FROM MILL (MILES)	COMPASS HEADING FROM MILL (DEGREES)	FORESTS SERVED
1	200.00	0.00	1 4
2	200.00	180.00	2 3

BETWEEN-FOREST RAIL DEALER LOCATIONS

RAIL DEALER #	DISTANCE FROM MILL (MILES)	COMPASS HEADING FROM MILL (DEGREES)	FORESTS SERVED
1	200.00	0.00	1 4
2	200.00	180.00	2 3

COST OF OPTIONS FOR EACH LANDING (CENTS PER CORD)
****

FOREST	LANDING	OPTION				
1	1	1 = 3175.01	2 = 1733.05	3 = 2293.95	4 = 2425.04	5 = 1935.01
		6 = 1722.39	7 = 2706.89	8 = 2945.71	9 = 2380.52	10 = 2078.17
		11 = 2359.24	12 = 2418.72	13 = 1491.97	14 = 1526.98	15 = 1600.25
1	2	1 = 3135.45	2 = 1723.90	3 = 2226.05	4 = 2315.06	5 = 1867.11
		6 = 1736.68	7 = 2711.01	8 = 2950.21	9 = 2384.64	10 = 2079.12
		11 = 2331.33	12 = 2306.74	13 = 1482.82	14 = 1511.28	15 = 1601.20
1	3	1 = 3063.45	2 = 1707.25	3 = 2012.45	4 = 2113.06	5 = 1653.51
		6 = 1575.28	7 = 2609.06	8 = 2695.91	9 = 2282.69	10 = 2055.55
		11 = 2037.74	12 = 2106.74	13 = 1466.17	14 = 1402.98	15 = 1577.63
1	4	1 = 3099.60	2 = 1715.66	3 = 2109.53	4 = 2217.05	5 = 1750.59
		6 = 1590.98	7 = 2528.32	8 = 2716.42	9 = 2301.95	10 = 2060.00
		11 = 2134.61	12 = 2210.73	13 = 1474.58	14 = 1418.68	15 = 1582.08
2	1	1 = 3016.46	2 = 1696.39	3 = 1999.89	4 = 2099.45	5 = 1622.14
		6 = 1643.91	7 = 2427.92	8 = 2625.08	9 = 2101.55	10 = 1763.80
		11 = 1971.25	12 = 1967.41	13 = 1455.31	14 = 1371.61	15 = 1562.72
2	2	1 = 3055.95	2 = 1705.52	3 = 2096.97	4 = 2203.45	5 = 1719.22
		6 = 1659.61	7 = 2379.64	8 = 2663.31	9 = 2253.26	10 = 2048.74
		11 = 2068.33	12 = 2071.41	13 = 1464.44	14 = 1387.31	15 = 1570.82
2	3	1 = 3090.20	2 = 1713.44	3 = 2213.46	4 = 2301.46	5 = 1835.74
		6 = 1675.31	7 = 2604.70	8 = 2690.65	9 = 2278.33	10 = 2054.54
		11 = 2134.84	12 = 2169.42	13 = 1472.36	14 = 1479.91	15 = 1576.62
2	4	1 = 3115.25	2 = 1719.23	3 = 2281.39	4 = 2411.43	5 = 1903.64
		6 = 1691.02	7 = 2600.54	8 = 2686.11	9 = 2274.17	10 = 2053.58
		11 = 2252.75	12 = 2279.39	13 = 1478.15	14 = 1495.61	15 = 1575.66
3	1	1 = 2982.66	2 = 1688.57	3 = 1988.58	4 = 2087.21	5 = 1622.14
		6 = 1643.91	7 = 2354.35	8 = 2473.03	9 = 2027.98	10 = 1746.79
		11 = 1957.38	12 = 1952.94	13 = 1447.44	14 = 1371.61	15 = 1545.71
3	2	1 = 3073.07	2 = 1709.48	3 = 2270.08	4 = 2399.19	5 = 1903.64
		6 = 1691.02	7 = 2559.61	8 = 2641.46	9 = 2233.23	10 = 1767.27
		11 = 2239.38	12 = 2264.92	13 = 1468.40	14 = 1495.61	15 = 1566.19
3	3	1 = 3027.32	2 = 1698.90	3 = 2202.18	4 = 2289.21	5 = 1835.74
		6 = 1675.31	7 = 2549.04	8 = 2629.94	9 = 2222.67	10 = 1764.83
		11 = 2171.48	12 = 2154.94	13 = 1457.82	14 = 1479.91	15 = 1563.75
3	4	1 = 2969.70	2 = 1685.58	3 = 2085.66	4 = 2191.20	5 = 1719.22
		6 = 1659.61	7 = 2393.60	8 = 2537.63	9 = 2067.23	10 = 1755.86
		11 = 2054.96	12 = 2056.93	13 = 1444.49	14 = 1387.31	15 = 1554.78
4	1	1 = 3127.22	2 = 1722.00	3 = 2221.02	4 = 2309.62	5 = 1867.11
		6 = 1736.68	7 = 2626.39	8 = 2714.32	9 = 2300.02	10 = 2059.55
		11 = 2192.46	12 = 2177.67	13 = 1480.92	14 = 1511.28	15 = 1581.64
4	2	1 = 3114.39	2 = 1719.03	3 = 2288.93	4 = 2419.59	5 = 1935.01
		6 = 1722.39	7 = 2591.47	8 = 2676.22	9 = 2265.10	10 = 2051.48
		11 = 2260.37	12 = 2287.64	13 = 1477.95	14 = 1526.98	15 = 1573.56

4	3	1 =	3049.28	2 =	1703.98	3 =	2007.43	4 =	2107.62	5 =	1653.51
		6 =	1675.28	7 =	2576.42	8 =	2659.81	9 =	2250.05	10 =	2048.00
		11 =	1978.37	12 =	1975.66	13 =	1462.90	14 =	1402.98	15 =	1570.08
4	4	1 =	3038.62	2 =	1713.12	3 =	2104.50	4 =	2211.61	5 =	1750.59
		6 =	1690.98	7 =	2612.41	8 =	2699.07	9 =	2286.04	10 =	2056.32
		11 =	2075.94	12 =	2079.66	13 =	1472.04	14 =	1418.68	15 =	1578.40

LEAST COST OPTION FOR EACH LANDING (CENTS PER CORD)
****

FOREST	LANDING	LEAST COST OPTION	COST OF OPTION
1	1	13	1491.97
1	2	13	1482.82
1	3	14	1402.98
1	4	14	1418.68
2	1	14	1371.61
2	2	14	1387.31
2	3	13	1472.36
2	4	13	1478.15
3	1	14	1371.61
3	2	13	1468.40
3	3	13	1457.82
3	4	14	1387.31
4	1	13	1480.92
4	2	13	1477.95
4	3	14	1402.98
4	4	14	1418.68

LEAST COST SHORTWOOD OPTION FOR EACH LANDING (CENTS PER CORD)
****

FOREST	LANDING	LEAST COST OPTION	COST OF OPTION
1	1	6	1722.39
1	2	6	1706.68
1	3	5	1653.51
1	4	6	1690.98
2	1	5	1622.14
2	2	6	1659.61
2	3	6	1675.31
2	4	6	1691.02
3	1	5	1622.14
3	2	6	1691.02
3	3	6	1675.31
3	4	6	1659.61
4	1	6	1706.68
4	2	2	1719.03
4	3	5	1653.51
4	4	6	1690.98

BIBLIOGRAPHY

LITERATURE CITED

1. Union Camp Corporation, "Industry Attains New Highs," The Digester, Savannah, Ga., Vol. 35, No. 1, Jan. 1970.

2. Dyer, Harry, "Woodhandling--The Last Frontier in the Battle to Cut Operating Costs," Paper Trade Journal, Sept. 13, 1965.

3. Rue, Leslie Waits, "A Simulation Model of the Southern Pulpwood Procurement System," A Thesis, Georgia Institute of Technology, School of Industrial Engineering, Nov., 1968.

4. Silversides, C. R., "The Influence of Mechanization on Harvesting and Transportation Methods," Pulp and Paper Magazine of Canada, Vol. 67, No. 10, Oct. 1966.

5. Stark, James J., "Paper Industry Analysis," A Term Paper, Georgia Institute of Technology, School of Industrial Engineering, undated.

6. Bromley, W.S., Pulpwood Production, American Pulpwood Association, 1968.

7. Prince, R. D., "Trends in Woodhandling...En Route," Paper Trade Journal, Sept. 13, 1965.

8. Rogers, Nelson K., "The Systems Aspects of Harvesting and Transportation of Pulpwood," Georgia Institute of Technology, School of Industrial Engineering, July 1, 1968.

9. Fenu, Pietro, "A DYNAMO Simulation of Long-Term Growth of the Southern Pulp and Paper Industry," A Thesis, Georgia Institute of Technology, School of Industrial Engineering, Dec., 1968.

10. Hurter, A. M. and Jelinek, V., "Trends in Woodyard Layouts," Paper Trade Journal, Sept. 13, 1963.

11. Davis, Kenneth P., Forest Management: Regulations and Valuation, New York: McGraw-Hill Book Company, 1966.

12. Hamilton, H. R., et al., "Phase Report on Factors Affecting Pulpwood Production Costs and Technology in the Southern United States," Battelle Memorial Institute, Aug. 1, 1961.

13. Barrish, Norman N., Economic Analysis for Engineering and Managerial Decision Making, New York: McGraw-Hill Book Company, Inc., 1962.

OTHER REFERENCES

Aitken, P.B., "Work Study in Logging--The Search for Better Ways," Pulp and Paper Magazine of Canada, Vol. 66, No. 6, June, 1965.

Berge, Claude and Ghauila-Houri, A., Programming Games and Transportation Networks, New York: John Wiley and Sons Inc., 1965.

Biggar, J. C. and Hannah, J. V., "Centralized Processing of Tree Lengths," Pulp and Paper Magazine of Canada, Vol. 67, No. 2, Feb., 1966.

Bromley, William S., "Pulpwood Procurement and Production," Handbook of Pulp and Paper Technology, New York: Reinhold Publishing Co., 1964.

Clark, J. D., "Pulpwood Hauling Analysis on the Limits of Northwestern Pulp and Power Limited," Pulp and Paper Magazine of Canada, Vol. 67, No. 2, Feb., 1966.

Hunter, A. M. and Jelinek, V., "Woodhandling and Preparation at the Mills--Lay-Out Requirements," Pulp and Paper Magazine of Canada, Vol. 67, No. 3, Mar., 1966.

Lussier, Louis-Jean, "Pitfalls in Logging Cost Analysis," Pulp and Paper Magazine of Canada, Vol. 66, No. 11, Nov., 1965.

McCracken, Daniel D., A Guide to ALGOL Programming. New York: John Wiley and Sons, Inc., 1967.

Page, G., "Loading, Trucking and Slashing Tree-Lengths on Quebec North Shore Paper Company Limits," Pulp and Paper Magazine of Canada, Vol. 67, No. 7, July, 1966.

Silversides, C. R., "Trends in Woodhandling...In The Woods," Paper Trade Journal, Sept. 13, 1965.

Stark, James J., Cosby, Walter W. and Rogers, Nelson K., "A Simulation Model for the Common Pulpwood Harvesting Systems of the Southern Pine Region," A Research Report, Georgia Institute of Technology, School of Industrial and Systems Engineering, 1969.

Thurman, D. H., Johnson, R. E. and Ham, R. J., ALGOL Programming...A Basic Approach, Burroughs Corporation, 1964.

Walbridge, Thomas A. Jr., "The Design of Harvesting Systems and Machines for Use in Pulpwood Stands of the Tennessee Valley as Dictated by Intensive Forest Management," A Dissertation, University of Michigan, 1960.